# Gear Noise Cause of a Different Stripe

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## QUESTION

**"It is very hard to find out any paper regarding 'tiger stripes' failure, created by electrical discharge current over the gear teeth." I wish to have some more information on this issue + how it affects the vibration / noise signatures; why does it creates the tiger stripes profile; how deep are the pittings; why does it create the noise and the possibility of running a gear with this failure?"**

### Expert response provided by Andy Milburn, Robert Errichello and Rainer Eckert.

The questioner is correct that there is not much published information regarding electrical discharge damage on gear teeth. We assume that they have already looked at (Ref. 1), since that is the only paper, we could find that uses the term "Tiger Stripes" for this failure mode (See Figure 1). The good news is that the reason there are not many papers on the subject is likely because it is not a common failure mode for gears. It is however very similar to "fluting" damage caused by electrical erosion on bearings and is much more common in bearings. Reference 1 does not directly address the questions above, so we will attempt to address them here.

First, we will discuss what the failure mode is. Tallian provides a good definition in (Ref. 2), "Electric Erosion is damage to contact surfaces caused by the passage of electric current." Other names used for the same failure mode are electrical pitting, electric current damage, current erosion, spark erosion, and electrical discharge damage (EDD). The damage can appear in two distinct forms; as periodic damage such as fluting or "tiger stripes" on gears, or as random distinct pits over an area of the surface (See Figure 2). For the remainder of this article, we will be concentrating on the first periodic form.

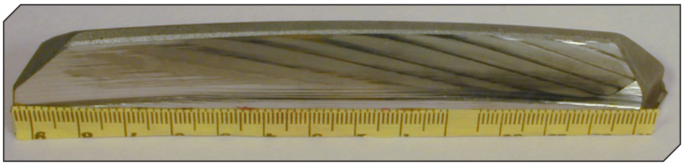

**Figure 1 An example of tiger stripes failure (this image appeared as Fig. 2a in Ref. 1).**

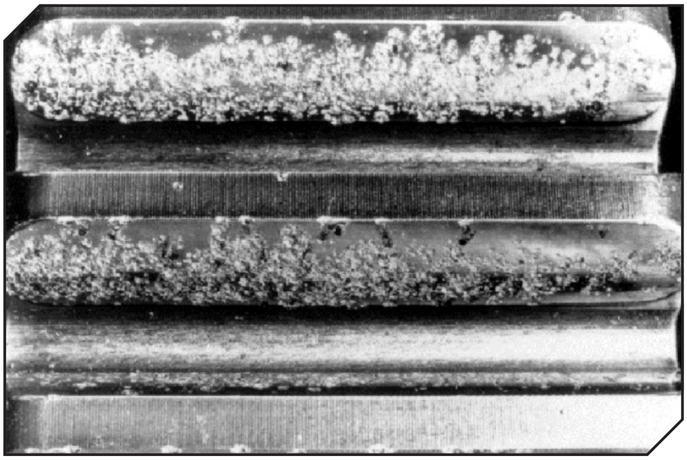

**Figure 2 Electrical discharge damage can also appear as random distinct pits over the area of the surface (this image appeared as Figure 20 in Ref. 3).**

The basic mechanism is the same for gears and bearings and can occur while they are static or rotating. Mating gear teeth and bearing component contacts consist of Hertzian contacts that are separated in some cases with a full EHL film and in many cases a partial EHL film plus some asperity contacts. Full EHL contacts and limited diameter asperity contacts result in resistance to the flow of electrical current and act as a capacitor. If an electrical charge builds across the contacts and reaches sufficient magnitude, the charge will jump from one component to another as a spark with sufficient energy to vaporize and melt one of the components. As the process continues, many small micropits are randomly generated on the surface. The morphology of the damaged surfaces generally consists of micropits with melted bottoms and globular material indicative of melting (See Figure 3). The critical magnitude of voltage differential across the contacts does not have to be large. Reference 4 states "Some sources (EPRI, etc.) suggest that voltages greater than 5V will result in EDM bearing damage." As more and more micro craters are created the surface to the unaided eye can appear frosted and the damage at first glance can appear to be micropitting, fretting damage or debris dents. To confirm that the damage is due to electrical erosion, the damage should be examined with a Scanning Electron Microscope (SEM) for the presence of melted material as shown in Figure 3. This same mechanism is used in Electrical Discharge Machining (EDM) to intentionally remove material to manufacture parts. The severity of the damage appears to be a function of the current magnitude and the time of exposure to the current. Cross sections taken through bearing races containing EDD (Refs. 5 & 6) indicate the pits are approximately 15 to 25 µm deep and there can be a heat affected zone with tempering up to 90 µm deep and in some cases re-hardened areas up to 50 µm deep. The re-hardened areas can be prone to cracking.As the process continues, the damage can develop into equally spaced valleys that on gear teeth appear as distinct lines parallel to the lines of contact (See Figure 1) and in bearings as periodic valleys transverse to the direction of rolling, which are called flutes (See Figure 4). The reason EDD eventually manifests as fluting is not kNown but it may be a combination of the electrical charge-discharge frequency in conjunction with the mechanical vibration that develops as the size and depth of the damaged areas increase.

The sources of the electrical current that cause EDD are many and varied but can be any source that generates a voltage difference across a bearing or gear. One of the main sources of bearing fluting damage are bearings in electrical motors that are controlled by Variable Frequency Drives (VFD) using Insulated Gate Bipolar Transistors (IGBT) for pulse width modulation of the frequency. These controllers vary the speed of AC motors by converting 60Hz current into current at different frequency, which varies the speed of the AC motor. However, the high frequency switching process can generate unbalanced voltages between the motor stator and rotor that then spark across the bearings supporting the rotor. These unbalanced voltages can also be transferred to connected equipment such as gearboxes. Other electrical sources that can generate damage are improper grounding during welding, lightning strikes, and static electricity generated by fans, belts, clutches, or oil filters.

The feasibility of continuing to run a component that has experienced EDD is dependent on several factors. The most important one being the consequences of a catastrophic failure. A component in a helicopter is much more critical than say a fan drive in an HVAC system. Any highly stressed Hertzian contact such as a bearing race, rolling element, or case-hardened gear that experiences a high rate of cycles should be replaced as soon as possible since the damage is likely to progress to macropitting (Ref. 7). However, if the damage is on a through hardened gear that is not in a critical application, and the source of electricity is eliminated, then the equipment could be allowed to run with periodic inspections. Any damage that has occurred on the tooth flanks could potentially self-correct by corrective pitting and the gear set could continue to run for a long time.

Advanced fluting damage on bearing races or rolling elements can produce significant noise because the rolling elements are basically running on a washboard type surface. We cannot discuss the vibration signature of a gear with periodic EDD because it is outside our area of expertise, but a gear mesh is going to generate noise because the valleys generated at the lines of contact are periodic and will produce an impact every time the mating tooth rolls/slides over the peaks and valleys of the EDD. Fretting damage along the lines of action on the high-speed pinion of wind turbine gearboxes similar to the EDD on the pinion in (Ref. 1), produced very high noise levels and all the pinions had to be replaced. The frequency of the noise is likely to be at the mesh frequency or some multiple of mesh frequency.

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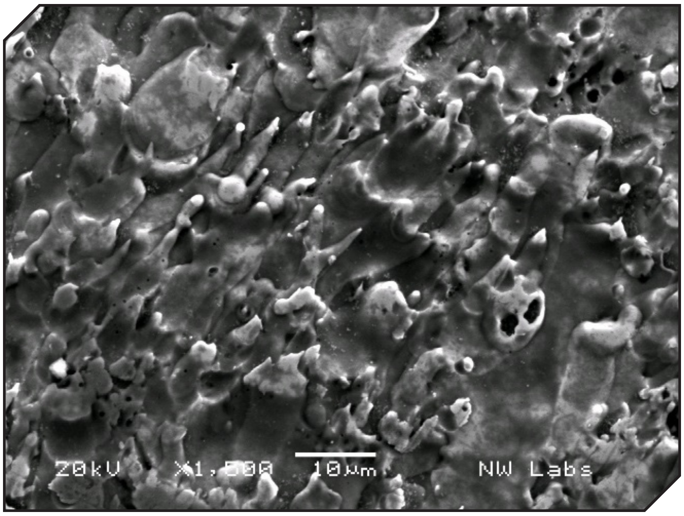


**Figure 3** The morphology of the damaged surfaces generally consists of micropits with melted bottoms and globular material indicative of melting (this image appeared as Figure 2d in Ref. 1).

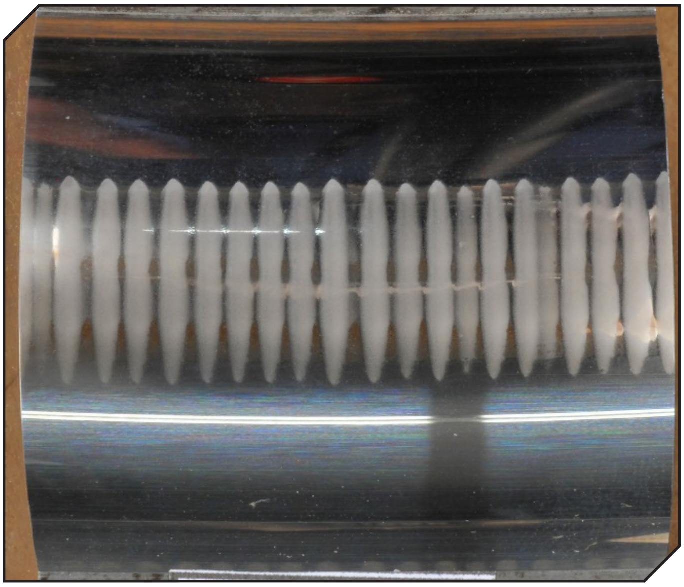

**Figure 4** Fluting on the outer race of a ball bearing.

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