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# Sub-Atomic Fatigue Failure

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**Abstract**: The intent of this document is to explain the effect of internal atomic fatigue failure and its implications on different field of science. The report explains the effect of repeated loading on sub atomic particles and its effect on the electric current generation/transmission. This report establishes governing fatigue equation for electric current generation and transmission. Detailed experimental study results are not part of this report.

**Keywords**: Atomic fatigue, Particles, Electric current

## I. INTRODUCTION

### Sub Atomic Particle Fatigue

#### Fatigue failure in stress analysis for metals:

In the early stages of failure prediction for metals, only a static loading was considered to predict failure. The static load applied on the given part is assumed to be constant over a period of time. The effect of the load applied previous to the current applied load, on failure of the part, is not accounted. In day-to-day applications, most of the parts have the load applied and removed many times. The applied load also may not be same each time. In case of the chair, when the chair is occupied, it experiences loading due to the weight of occupant. When the chair is empty, the load is released.

When this single load instance is considered, there is some internal resistance to the load that is developed in the chair. This internal resistance is called stress. The parts that are used to make the chair are made of certain known material. If the chair is made of steel, there is a tested amount of stress allowable (Tensile, Compressive, Shear etc.,) that the material can withstand. This allows the prediction of failure based on static load.

However, the chair is occupied and let free often/repeatedly. Every time the chair is occupied, a stress develops and there will be some micro internal damage to the part. This damage keeps adding up as the chair is loaded and unloaded repeatedly. When the total damage reaches critical level, a crack initiates on the chair.

Similarly, in the aircraft industry the stress analysis in the early times were based on static loading. The design of the airframe was validated with predicted static loading during flight. But the structure was failing well below the predicted life. When the stress levels were studied, it was shown that the failure happens at much lower stress levels that what the material was supposed to withstand. Like the chair analogy, it was found that the failure was due to repeated loading and unloading [1].

This Phenomenon was called as fatigue failure. In short, a material can fail well below the static allowable stress level when the loading is repetitive. The Fig. 1 below shows the fatigue initiation in a rectangular cross section followed by crack growth and fast fracture.

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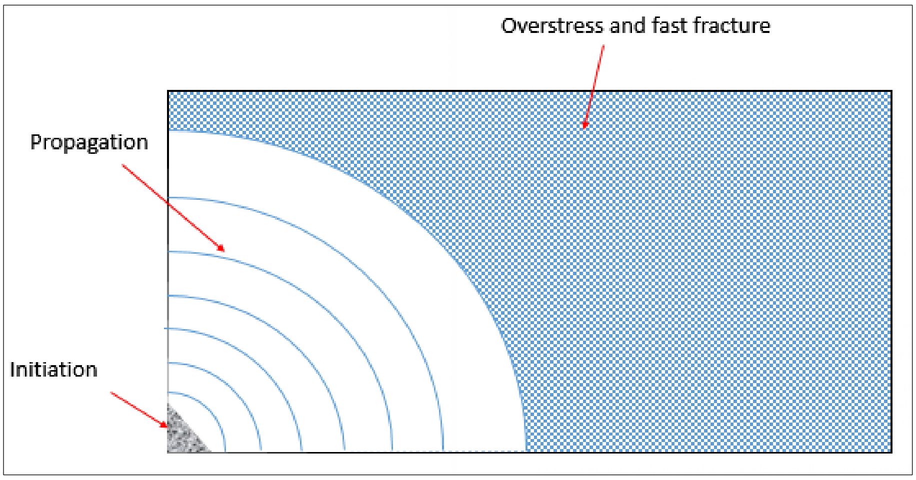


**Fig. 1.** Fatigue failure in metals.

This is at the macro level. There is a reasonable understanding of fatigue failure at macro level and there are analytical methods to predict the failure of any material under repetitive loading. While there is good understanding of fatigue concept in materials as a whole, the understanding of fatigue in micro level is important.

When there is a fatigue failure at macro level, there is fatigue failure at the sub atomic level. The influence of fatigue loading in the field of electric current is explained herein.

**Fatigue in case of atoms and its significance in electrical engineering:**

An AC/DC generator is used to generate electricity. The AC/DC generators usually use copper windings. When this copper winding cuts the magnetic field repeatedly, electricity is produced. As is known, electricity is caused by the movement of electrons through a conductive material [2].

If a copper winding is exposed to a constant static magnetic field, there is no significant potential voltage produced. Whereas when the winding cuts the magnetic flux periodically, there is continuous electric current and significant potential voltage. The generation of electric current is not in itself due to fatigue phenomenon though.

As explained previously in the chair example, when the atom is exposed to a magnetic field, the electrons in the atom tend to be influenced by the field force and as a result try move away from the atom. When a certain amount of static magnetic force is applied, few electrons that have week bonding with the atom moves away. Thus creating a small amount of electric charge. It is not necessary that the electrons in the outer most shell/lowest energy level of all the atoms should move away immediately with the application of magnetic field once (Static field). As mentioned earlier, few electrons that have week bonding tries to move away causing a small charge.

At the same time the electrons that have relatively stronger bonding tries to move but is held by the binding force of the atom (With nucleus) and an internal resistance is developed. As a result, the atom experiences internal atomic stress. For the electron to break away from the bond, the applied magnetic field should create a very high internal atomic stress, which is more than enough to overcome the binding force. This is very high depending on the configuration of the atom. The binding force mainly depends on the size of the nucleus and distance of the electron from the nucleus/energy level. It also depends on the nature of binding force (Elasticity of the binding force).

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**Determination of the Factors Affecting Sub Atomic Fatigue**

If the magnetic force is applied repeatedly this causes the electron to overcome the binding force at a much lower applied force. This phenomena is be termed at electron fatigue. When a material like copper or aluminum is exposed to repeated magnetic force, the number of free electrons released is higher and causes higher potential voltage [3,4]. The electron also gains high kinetic energy with repeated application of magnetic field. Fatigue loading plays significant role in increasing the kinetic energy of the electrons.

Three major factors that affect the electron fatigue stress are as follows. The electron fatigue stress is directly proportional to the magnetic field strength and the number of cycles.

- Magnetic field strength, F (Tesla)
- Number of cycles the field strength changes, N (Cycles)
- Field ratio, R (Ratio of the southern pole field force to the norther field force assigning a negative sign to the southern pole force)

The third factor mentioned above (Field ratio) plays an important part in fatigue failure. When the force is applied in both direction one after the other, the easier it becomes to break the bond.

If we bend a plastic bar in one direction with some specific force, the bar bends and yields, may not break. When we bend the same bar in other direction, it still yields on other side and bends. If we keep repeating the process, the bar finally breaks at much lower loading. This fatigue failure phenomena applies to the electrons as well. When the electrons are forced to move in one direction and then in the other direction repeatedly, it`s easier to break the bond that exists with the nuclei. The magnetic field causes the free electron to move causing the electric current. But the fatigue phenomena forces more electrons with week bond to break away from the atom causing a net charge for the atom and hence causing high potential voltage. It has to be noted that the generators/alternators work with a field ration of -1 which helps in causing fatigue failure. A field ratio of 1 means that the field loading is static and does not cause any fatigue damage in electron bonding. In transmission lines, the ratio is defined in terms of the ratio of movement of electrons in one direction to the other (Electron flow ratio). The electron flow ratio plays the same role as the field ratio, throughout the conductive material in which the electron flows (Figs. 2 and 3).

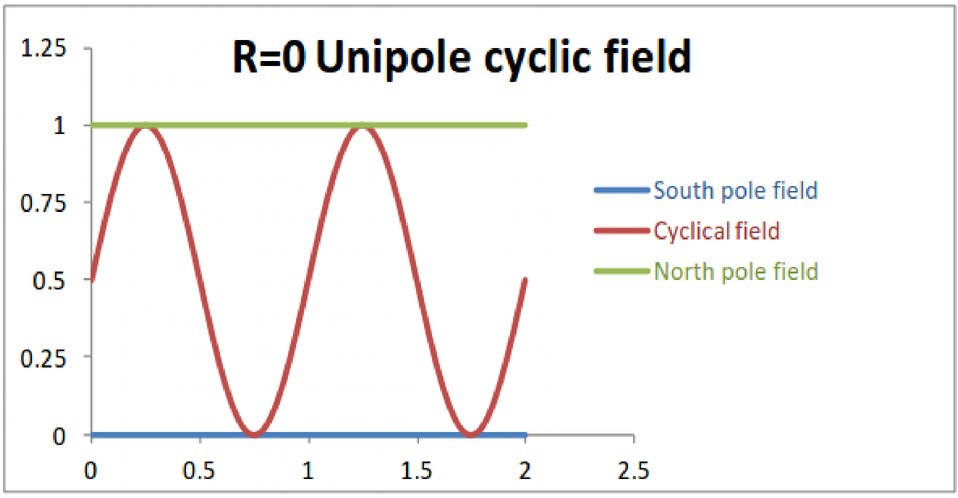


**Fig. 2.** Single pole fatigue cycling.

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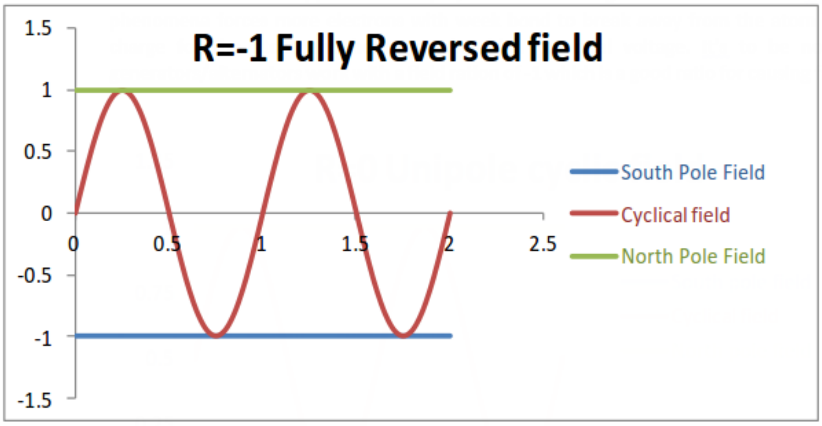


**Fig. 3.** Bi pole fatigue cycling.

In the transmission of electric current, the following factors play a significant role.

- Electron flow ratio ($E_f$) (It is usually 1 for direct current and -1 for alternating current)
- Rate of flow of electrons (Current, I Amps)
- Material constant $m_c$ (Directly proportional to conductivity)
- Potential voltage (V)

Negative electron flow ratio in the case of alternating current induces more internal atomic stress throughout the conductive material when compared to direct current. This results in more number of electrons being detached from the atom. With more negatively charged free electrons repelling each other, the resistance to flow increases. The additional electrons released locally in the conductive material from the atom does not have enough kinetic energy to move through the conductive material and stays local to the zone from where the electron is released. It is to be noted that the more electrons released from the atom locally, more the repulsive force and hence more the resistance to flow.

**Additional Consideration for Sub Atomic Fatigue Failure**

The other important aspect is the frequency of the field reversal. The electrical generators usually operate in low frequency (Less than 1 KHZ). At low frequencies, the internal atomic stress is more and the fatigue damage is also more. At much higher frequency, the internal-atomic stress is low and fatigue damage is also low.

Every time the magnetic force is applied on the atom the bond sustains damage. When the magnetic force is applied once and is constant, the damage remains unchanged and the electrons are still bound to the atom. When the magnetic force is applied many times repeatedly, the damage sustained during every application sums up. Finally, the damage sustained is high enough to break the bond with the nucleus. This happens much faster if the magnetic force is reversed periodically. This results in high potential voltage. Similarly, the electrons moving in the conductive material exerts a force on the atoms that are still bound to the atom. Similar to the field ratio, a negative flow ratio (Where the electron flow reverses direction periodically) induces more force on the electrons that are bound to the atom. This is more severe than having a positive flow ratio. More electrons are released from the conductive material where the flow ratio is negative. In the alternating current, the electrons are forced to move in both the directions throughout the conducting material. This causes more electrons to be released from the atom locally than the direct current where the electron moved only in one direction. The field ratio plays an important part in the process of more electrons released locally within the conductive material.

In addition to the parameters given previously, the following parameters affect the internal-atomic stress [5,6] (Internal to the Generator/Alternator with applied magnetic field).

Material internal-atomic fatigue constant– m (Ability of the material to react to magnetic field)
Total Surface area exposed to magnetic field – A, $in^3$
Length of the material exposed to magnetic field – L, (in)

As we can see above the number of electrons that are released depends on many factors. The important factor is the magnetic field force. The fatigue life curve called as S-N curve for materials is as shown in below Fig. 4.

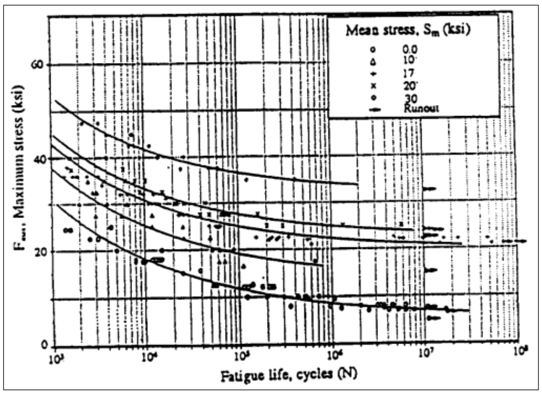


**Fig. 4.** Stress vs. life to failure in metals.

As it can be seen above, for metals, the number of cycles to failure is driven by the alternating stress and mean stress applied on the part. The stress ratio also affects the fatigue life significantly. Every time a load is applied, damage is caused to the part. This can be seen as damage at the micro level. Every time a load is applied, it forces few molecules to break away. When repeated loading is applied, the damage is caused every time and it adds up. At one point, all the molecules separate and this cause the failure of the part. This analogy can be applied at the sub atomic level. There are a minimum number of cycles that is required to break the bond at any given energy level. There is also minimum required field strength to cause sufficient damage. If the magnetic field strength is below the required threshold limit (Electron endurance limit), there will not be any significant electron movement or voltage. This minimum required field strength is driven by the force/energy required to break the weakest bound electron from the atom.

It is possible to break the electrons in higher energy level with fatigue loading. The number of cycles to break the electron in the higher energy level and the field strength required is very high as the binding force is high. Based on the above mentioned observations, the following relation is obtained for electric current generation and transmission.

Governing equation for electron fatigue principle:

$$\text{Voltage Produced} \propto F \times N \times c \times (1\text{-}R)^{m} \times A \qquad (1)$$

Material constant m is always more than unity and inversely proportional to material resistance.
Field ratio constant c varies based on material properties and to be established by test.

$$\text{Transmission efficiency } \varepsilon = \frac{V \times m_c}{I \times (1 + (1 - 0.5 \times E_f))} \qquad (2)$$

Understanding the internal-atomic fatigue stress and sub atomic fatigue could lead to major advancement in the several fields.

## II. PRACTICAL APPLICATIONS OF THIS THEORY

### Electric Current Generation and Transmission

The principle of internal atomic stress and sub atomic fatigue explained in this document helps in optimize the design of electric generator/transmission systems. By varying the field force, frequency and the field ratio an optimum configuration is obtained for a given voltage output (Upto 20% increase in efficiency is observed). Understanding the sub atomic fatigue and internal electron stress through this report brings new perspective in terms of material selected for the generator/alternator. In general, the material properties differ based on the temper, form and alloy composition. Orienting the coil in a way that the flux is across the weaker direction (Applicable to certain form of materials) improves the efficiency of the motors considerably (By 10 to 20%). Also selection of material that has lower allowable internal electron stress also improves the efficiency of the generators considerably. The result of experimental study is not published intentionally in this document.

### Nuclear Physics

Fatigue failure technique reduces the energy required to create the nuclear reaction. Using repetitive damage and reversed loading, the energy required for creating the nuclear reaction is reduced significantly thereby improving the efficiency of the nuclear reactors.

Technology that involves energy from sub atomic particles and that relies on impact energy or heavy static force for energy release is more efficient when fatigue loading is used to cause energy release.

## III. CONCLUSION

Explanation of internal atomic stress state and internal atomic fatigue failure open up new possibilities to optimize various existing technologies. A detailed study of the atom internal behaviour with fatigue loading helps to save the energy wasted otherwise due to low efficient design in its current form. This paper intentionally does not cover all the fields that would benefit from this field of study to keep the core theory simple to understand. Results of detailed experimental study of each of the parameters is not published in this report intentionally as the intention of this report is only to explain the basics of sub atomic fatigue failure.

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