Fragmentation of Thin Wires Under High Power Pulses and Bipolar Fusion

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Abstract: In this article we present an alternative explanation of the phenomenon of wire fragmentation under high transient currents based on classical electromagnetism. We also explain how this phenomenon can be utilized as a primitive example of low energy-high power disruptive phenomena that can affect even nuclear matter.

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Introduction

In the proposed paper we will present an alternative explanation of the phenomenon of wire fragmentation under high voltage pulses based on classical electromagnetism. For this phenomenon several explanations have been proposed (see [1,2,3,4,5]) that to our opinion are inadequate or incomplete.

In a number of experiments with high currents, performed at the 80's, the phenomenon of wire fragmentation was found to take place before evaporation of the wires. This phenomenon although not yet fully understood is currently utilized in the field of fusion research in the well known Z-Pinch machines in Sandia Labs and other places worldwide. There, use is being made of the explosive behavior of heavy loaded current carrying wires to exert an inward pressure upon a fuel pellet in order to reach fusion pressures and temperatures.

Several theories were proposed over the years to explain the anomalous behavior of such thin wires with respect to the peculiar way the fragmentation occurs. One of the first reports on the subject is by Nasilowski [1] as early as 1964. Graneau et al. [2],[3],[4] have conducted several experiments around 1980 and concluded that there should exist certain deviations from the ordinary Maxwell-Lorentz force law. In fact, they have subsequently proposed an alternative "Galilean" type of electrodynamics favoring Action-at-a-distance and longtitudinal forces of the old Ampere type. There were also attempts to derive such forces from Weber electrodynamics which remain controversial.

Aspden [5] proposed an alternative explanation based on electromotive forces due to the self-inductance of the wires. Rambaut et al. [6],[7] on the other hand found a plausible microscopic explanation in terms of the Fermi distribution of the electron gas in the metallic crystal lattice and the associated retarded Lienard-Weichert potentials justifying the accepted Maxwell Einstein picture of electrodynamics. Several other issues though remain problematic as the strong X-ray emissions up to 100Kev and even neutron emissions. Recently, Winterberg [8] has come up with a revival of Schwinger's sonoluminessence theory to propose that background vacuum energy was actually responsible for the explosive character of the effect due to spontaneous depressurization of small bubbles of increased vacuum energy density inside the metal. Molokov et al [9], [10] also try to reproduce the fragmentation effect based on more classical mesoscopic treatment including thermo-plasticity and pinch effects due to the abrupt radial inward compression of the magnetic field lines at the onset of the current flow.

As it will be shown by the proposed analysis the high transient currents produced by these high voltage pulses can form transient steady waves on the wires, acting as transient antennas, the basic harmonic of which is creating excess bipolar Coulombic forces between its opposite pulsating parts.

We also explain how this phenomenon can be utilized as a primitive example of low energy-high power disruptive phenomena that can affect even nuclear matter. The produced fusion effects have already been experimentally realized by many researchers see [6,7,8,9] however due to lack of proper explanation of the origin of the high forces they could not be used for fusion applications of practical importance.

The fragmentation mechanism

Previous studies both experimental and computational showed that the overall fragmentation phenomenon is complex depending on the time scales of observation as well as the particular experimental conditions. Formation of plasma around the wires [10],[11] as well as striation of the conductor materials [12] appear depending on the time scale of the observation which may be up to 100 ns. In our analysis we will concentrate in the initial stages of the effect and for times less than 1 ns in order to examine the initial formation of a standing wave across the wire length just before the occurrence of the first stage of the fragmentation process.
We assume that a high voltage pulse is effected on a thin wire of length L and diameter D satisfying $L >> D$. If the time width of the pulse is extremely small as in the case of appropriate special switches the power can become significantly high. In such a case it is expected that this short lasting pulse will have its energy spread over a characteristically broad spectrum of harmonic frequencies related to the fundamental wave length equal to L. A fundamental assumption in what follows is that after an extremely small time interval, equal to a multiple of the length of the wire divided by the speed of light, the initial energy of the pulse should be concentrated in the first strong harmonics. Thus the transient voltage pulse leads to a set of transient standing electromagnetic waves of wavelengths submultiples of L. A major part of the pulse energy will be in the transient fundamental harmonic with the characteristic wave length L of the thin wire. During this very short period of time the thin wire is acting as a transient linear antenna that can be studied using the Maxwell equations standard analysis. This transient phenomenon will last a few periods during which its energy will be transformed in ohmic losses plus radiation.

For example if the wire has a length L of 12cm the period is of the range of L/c ,where $c = 3.10^8\, m/\sec$, thus the transient phenomenon will last some multiples of 0.4 nano seconds. This is used here as the main arguments that even if certain attenuation phenomena would be present in the long time limit they will play no role at the timescale of the main fragmentation process. In order to analyze the situation from the point of view of the forces developed across the antenna wire we concentrate on the fundamental harmonic which will have the major transient force effect. This is a transient standing electromagnetic wave of wavelength L.
Let us consider two adjacent pieces of wire of length $L/2$ under such a transient standing electromagnetic wave. Then the current of this transient standing electromagnetic wave current along the z axis will be given by

$$I(z,t) = \mathrm{Re}\left\lfloor \sqrt{2}I \exp(\mathbf{i}\omega t)\sin(kz)\right\rfloor \qquad (1)$$

with $k = 2\pi / L, c = \omega / k = 3.10^8$ m/sec. If we divide this antenna into small infinitesimal dipoles of length dz_1 then all dipoles from the first half wavelength (upper part of the antenna) are oppositely oriented to the rest of the dipoles for the other half wavelength. We may then assume that every such dipole dz_1 creates an electric field $dE_{12}(z)$ affecting every dipole dz_2 at the lower part of the wire and at distance z_{12}. We show this schematically in Fig. 1.

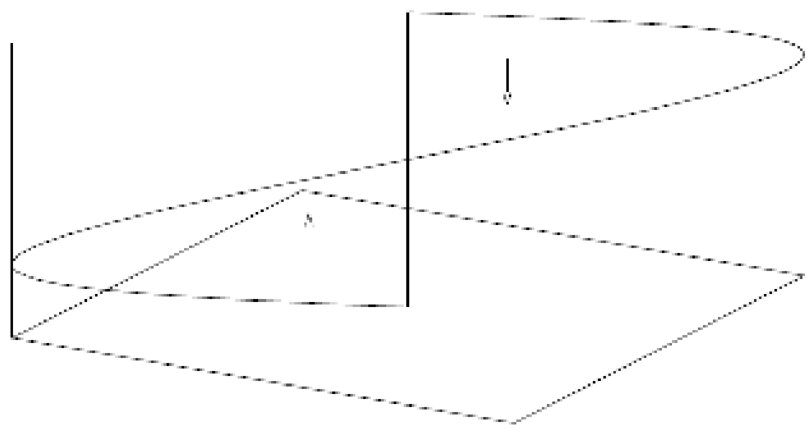

Figure 1

According to standard formulas for radiating dipoles we can write the total field of each elementary dipole in space as:

$$E_r = Z_0 \frac{2Ik^2 dz}{4\pi} \cos\theta \left[(\mathbf{i}kr)^{-2} + (\mathbf{i}kr)^{-3} \right] e^{-\mathbf{i}kr}$$
$$E_\theta = Z_0 \frac{Ik^2 dz}{4\pi} \sin\theta \left[(\mathbf{i}kr)^{-1} + (\mathbf{i}kr)^{-2} + (\mathbf{i}kr)^{-3} \right] e^{-\mathbf{i}kr} \tag{2}$$

where $Z_0 = \sqrt{\mu_0 / \varepsilon_0} \cong 120\pi$ the impedance of free space. For θ = 0 we find the total contribution across the z axis as

$$dE_{12} = 2Z_0 \frac{I(z_1)k^2 dz}{4\pi} \left[(\mathbf{i}kr)^{-2} + (\mathbf{i}kr)^{-3} \right] e^{-\mathbf{i}kr} \tag{3}$$

Taking the imaginary part as the reactive power obtains

$$dE_{12} = \mathbf{i}k^2 \frac{I(z_1)dz_1}{2\pi} \sqrt{\frac{\mu_0}{\varepsilon_0}} \left[\frac{\cos(kz_{12})}{(kz_{12})^3} + \frac{\sin(kz_{12})}{(kz_{12})^2} \right] \tag{4}$$

From the above we can find the mutual reactive power between the two dipoles as

$$dQ_{12} = 2\,\mathrm{Im}\left[dE_{12}(z_2) I(z_2) dz_2 \right] \tag{5}$$

where the factor of 2 is to take into account the two equal and opposite actions from dz_1 to dz_2 and vice versa.

$$dQ_{12} = 60k^2 I(z_1) I(z_2) f(z_{12}) dz_1 dz_2 \tag{6}$$

where

$$f(z_{12}) \approx \frac{\cos(kz_{12})}{(kz_{12})^3} + \frac{\sin(kz_{12})}{(kz_{12})^2} \tag{7}$$

Then we may find the pulsating electromagnetic energy of frequency 2ω and through it the force between the dipoles via the definitions

$$dW_{12} = \frac{dQ_{12}}{2\omega}, dF_{12} = -\frac{\partial(dW_{12})}{\partial z_{12}} = -\frac{k}{2\omega} \frac{\partial(dQ_{12})}{\partial(kz_{12})} \tag{8}$$

This leads to a constant direction component of a repelling force which is given as

$$dF_{12} = -\left(\frac{1}{2c} \right) 60k^2 I(z_1) I(z_2) \frac{\partial f}{\partial(kz_{12})} dz_1 dz_2 \tag{9}$$

$$dF_{12} = -\frac{180}{c} \sin(kz_1) \sin(kz_2) \Phi(kz_{12}) d(kz_1) d(kz_2)$$
$$\Phi(\chi) = -\left[\left(\frac{1}{\chi^4} - \frac{1}{3\chi^2} \right) \cos\chi + \frac{1}{\chi^3} \sin\chi \right] = \Phi(|\chi|) \tag{10}$$

Estimation of electromagnetic forces

Based on the fundamental result given by (10) we can estimate the repelling force between the upper and the lower part of the antenna by direct integration

$$F_{12} = -\frac{180}{c} I^2 \int_0^{\pi} dx \sin x_1 \int_{\pi}^{2\pi} dx_2 \sin x_2 \Phi(x_1 - x_2) \quad (11)$$

In the above we have put $x_1 = kz_1, x_2 = kz_2$.
The distance of the dipoles can be approximated for small diameters in comparison to wire length as:

$$| x_1 - x_2 | \approx \sqrt{(x_1 - x_2)^2 + (kD)^2}, kD = 2\pi D / L \quad (12)$$

Then the force is given approximately by:

$$F_{12} = -\frac{180}{c} I^2 \int_0^{\pi} dx \sin x_1 \int_{\pi}^{2\pi} dx_2 \sin x_2 \Phi(x_1 - x_2) \quad (12)$$

or

$$F_{12} = -\frac{180 I^2}{c} \varphi(kD) \quad (13)$$

The integral $\varphi(kD)$ was numerically evaluated in MATLAB named as "Tensile Force Factor" and the force was calculated with respect to the parameter $L / D = 2\pi / kD$ as shown in Fig. 2. Thus the "bipolar" repelling force between the upper and lower parts of a wire of a given length can be calculated for given values of the diameter.

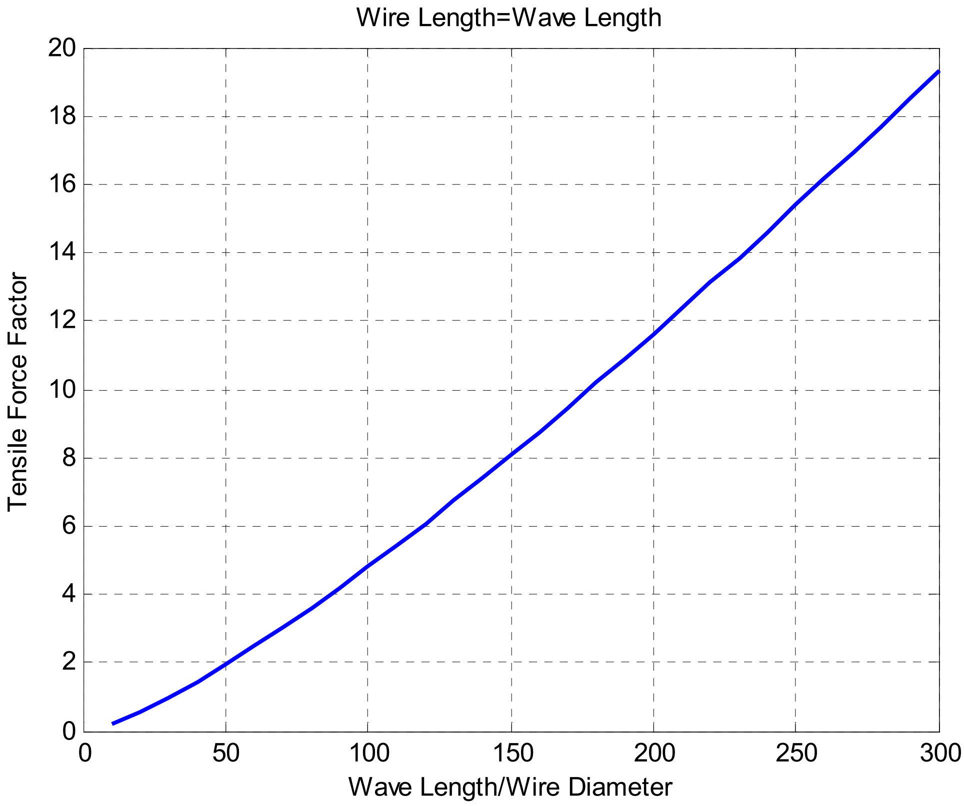

Figure 2

We should notice that when the length x_1 and x_2 become comparable to the diameter D the distance between adjacent dipoles $| x_1 - x_2 |$ should be calculated with a smaller effective diameter. This could be incorporated with an appropriate empirical coefficient such that $D_{eff} = c_1 D, c_1 < 1$.

Using the same approach the repelling force on the set of dipoles around dx in one half of the wire in a distance x_1 off the centre of the wire (calculated in wire diameters) arising by all the dipoles of the other half of the wire by the formula:

$$F(x_1) = -\frac{180}{c} I^2 \sin x_1 \int_{\pi}^{2\pi} dx_2 \sin x_2 \Phi(x_1 - x_2) \qquad (14)$$

This function was numerically evaluated for various values of x_1 (in wire diameters) and its values (as % of the maximum value) are shown in Fig. 3 for a wire length equal to 200 wire diameters.

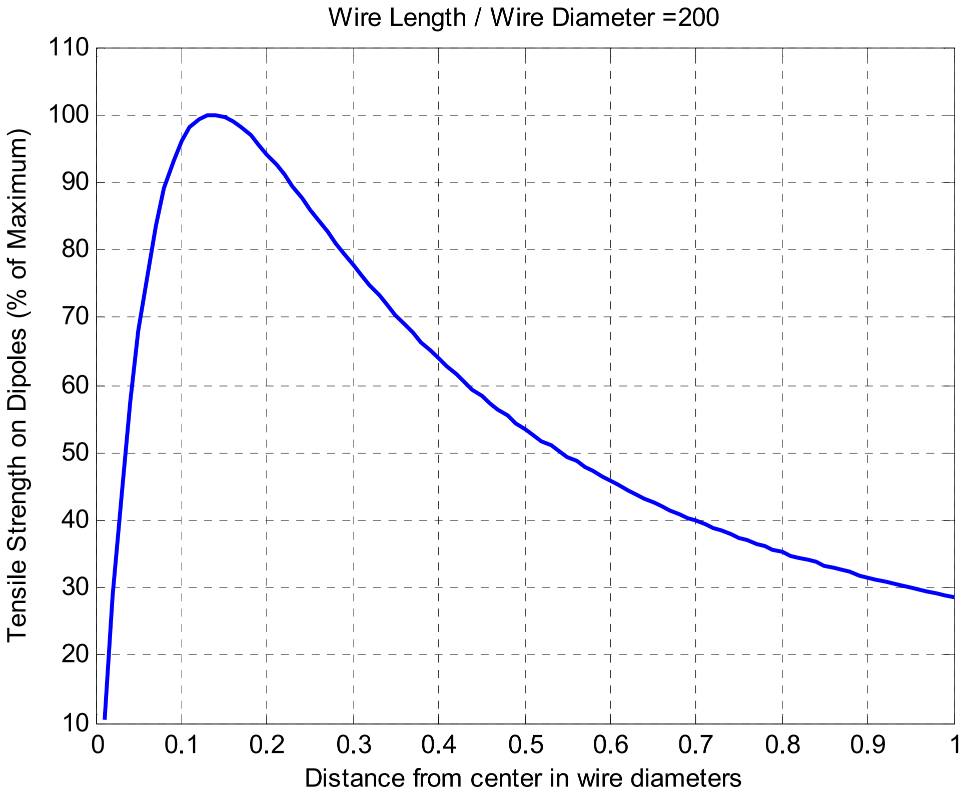

Figure 3

From the data of Fig. 3 it is evident that the maximum repelling force is exercised on the dipoles near the centre of the wire. That explains the expectation that the first crack on the wire due to dipolar repelling force will appear near the centre of the wire. It also agrees with experimental evidence from the heavy water drill apparatus where half of the heavy water is expelled during its operation [13]. From what appears to be the case, the quantity of the expelled water leaving the drill tube comes from the second half of the tube and gets separated near the middle of the tube while the other half which is pushed backwards remains in the interior of the tube.

Conclusions

We strongly believe that the proper electromagnetic explanation of the onset of fragmentation phenomena due to high bipolar forces arising by the transient steady currents on the wire under high voltage pulses can lead to fine tuning of proper electromagnetic devices that could generate "bipolar fusion" phenomena in energy and thrust applications of major importance. The study and design of a proper device generating fusion of heavy water under normal temperature conditions is under research.

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