Dipole Electromagnetic Forces on Thin Wires under Transient High Voltage Pulses

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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.

Keywords : wire fragmentation, fusion

PACS Code : 52.80.Qj

1. Introduction

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. However, several other issues remain problematic as the strong X-ray emissions up to 100Kev and even neutron emissions.

Recently, Winterberg [8] came up with a revival of Schwinger's sonoluminessence theory to propose that background vacuum energy was actually responsible for the

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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.
In this report we present evidence that a macroscopic explanation of these phenomena is indeed possible solely in terms of classical electromagnetism. In the next section, we prove that the forces contained in the original Maxwell tensor suffice to reproduce the strange longitudinal compression effects and can be obtained by the reactive power of the near field energy. In section 3, we argue that such forces are microscopically equivalent to Coulombic dipole forces. Their transient character can become so high that there might even allow for interactions between nuclear matter thus being plausible candidates for alternative low energy and high power micro-fusion devices.

2. The main fragmentation mechanism

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 argument. Even if certain attenuation phenomena would be present in the long time limit they will play no role on timescale of the main fragmentation process.
The general analysis for the calculation of the current distribution on a linear antenna is a boundary value problem of high complexity. However if the wire is thin, i.e. its diameter is much smaller than its length L, it can be assumed that several harmonics related with its length L can be appeared under a short duration transient voltage excitation with the fundamental harmonic frequency ω related to the length L by the relations: $k = 2\pi / L, \omega \approx c \cdot k, where: c = 3.10^8 m/\sec$ m/sec.
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 support the major transient force effect. This is a transient standing electromagnetic wave of wavelength L.

Let us consider two adjacent pieces of a thin wire of length *L/2* under such a transient standing transient electromagnetic wave. Then the current of this transient standing electromagnetic wave current along the z axis will be given by

$$I(z,t) = \mathrm{Re}\left[\sqrt{2}I\exp(\mathbf{i}\omega t)\sin(kz)\right] \qquad (1)$$
$$Thus: I(z) = I\cdot\sin(kz)$$

If we divide this thin 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.

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

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

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

$$dE_{12} = 2Z_0\cdot\frac{I(z_1)\cdot k^2\cdot dz_1}{4\pi}\cdot\left[(\mathbf{i}kr)^{-2}+(\mathbf{i}kr)^{-3}\right]\cdot e^{-\mathbf{i}kr} \qquad (3)$$

Taking the imaginary part of dE_{12} as the reactive power yields

$$Jmag[dE_{12}] = \mathbf{i}k^2\cdot 60\cdot I(z_1)\cdot dz_1\cdot\left[\frac{\cos(kz_{12})}{(kz_{12})^3}+\frac{\sin(kz_{12})}{(kz_{12})^2}\right] \qquad (4)$$

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

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

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

$$dQ_{12} = 120\cdot k^2\cdot I(z_1)\cdot I(z_2)\cdot f(z_{12})\cdot dz_1\cdot dz_2 \qquad (6)$$

where

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

Then we may find the pulsating electromagnetic energy of frequency 2ω and through it the steady component of 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

$$dF_{12} = \left(\frac{1}{2c}\right)\cdot 120\cdot k^2\cdot I(z_1)\cdot I(z_2)\cdot\frac{\partial f}{\partial(kz_{12})}\cdot dz_1\cdot dz_2 \tag{9}$$
$$= \frac{180}{c}\cdot\sin(kz_1)\cdot\sin(kz_2)\cdot\Phi(kz_{12})\cdot d(kz_1)\cdot d(kz_2)$$

Where:

$$\Phi(\chi) = -\left[\left(\frac{1}{\chi^4}-\frac{1}{3\chi^2}\right)\cos\chi + \frac{1}{\chi^3}\sin\chi\right] \tag{10}$$

Hence, between the upper and the lower part of the antenna there should exist a repelling force given by direct integration of the above as

$$F_{12} = \frac{180}{c}I^2\int_0^{\pi} dx\cdot\sin x_1\cdot\left[\int_{\pi}^{2\pi}\sin x_2\cdot\Phi(x_1-x_2)\cdot dx_2\right] \tag{11}$$

Where: $x_1 = kz_1, x_2 = kz_2$.
The distance of the dipoles can be approximated for small diameters as

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

Therefore the force is given approximately by:

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

Or:

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

The integral φ was numerically evaluated in MATLAB and the force was computed with respect to the parameter $L/D = 2\pi/kD$ as shown in Fig. 1. Thus the repelling force between the upper and lower parts of a wire of given length can be calculated for certain values of the diameter. Taking into account the tensile strength of a thin wire from mild steal which is of the order of 250 MPa, we find from the data of Fig. 2 that for a 20mm length of wire of a diameter of 1 mm we get a break force above the limiting value for

$$\sim 12\frac{180}{c}I^2 \geq 250\times10^6\left(\frac{\pi d^2}{4}\right) \tag{14}$$

or $I \geq 5.2KA$.
It is possible that when the length becomes 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 $D_{eff} = c_1 D, c_1 < 1$.

3. Theoretical considerations

1. The main assumption in our model of transient phenomena is that electromagnetic resonance is responsible for the energy concentration in standing electromagnetic transient wave modes of which the first one is the most significant. This becomes evident given the nature of the actually observed phenomenon and it has been checked with stroboscopic examination of the real time evolution of the phenomenon. Although in practice it is difficult to observe whether the wire fragmentation has been initiated with a first crack occurring near the center of its whole length, there is an experiment that makes this obvious. If instead of a thin wire a linear fuse full of heavy water is stroked by the high voltage transient pulse half of the water is forced to expel by the fuse [6]. Thus we strongly believe that the wire fragmentation starts near the middle of the wire while subsequent cracks appear in the remaining parts more or less symmetrically. If one also accounts for small deviations due to possible defects in the crystal lattice, then this is the kind of behavior expected from the mechanisms proposed above. In fact, we propose a scenario according to which, the fist fundamental harmonic is responsible for affecting the first crack near the center as this is the neutral surface at which the repelling dipole Coulomb forces between the charges are effected. Subsequent cracks are also due to the same mechanism by the next harmonics of the remaining parts of half length etc.
The energy for effecting the cracks on the subsequent fragments comes from direct induction between the neighboring pieces of wire as most of the energy has not yet been radiated away due to the extremely short time interval during which the phenomenon evolves. The phenomenon is expected to last for so long as the ratio L_n/D gets significantly higher than 1. When these two magnitudes approach each other, the harmonics become too small and the forces deviates from z axis.
2. It has been observed in real experiments that such transient pulses are often responsible for X-ray and even neutron emissions. Although detailed examination of these phenomena becomes increasingly difficult as the time scale decreases, it seems obvious that they must be associated with both the overall motion of the electron plasma in the metal lattice beyond the fundamental gyroscopic plasma frequency as well as with some not well studied interaction with nuclear matter. High speed electron collisions as well as resonant cavities can justify the X-ray emission but the neutron radiation suggests that strong dipole Coulomb interactions may become temporarily so strong that can affect even the energy barriers inside the nuclei.
As a matter of fact, *pyroelectric fusion* has been proposed as early as 1932 by Cockroft and Walton who used their generator to demonstrate that fusion can occur in deuterated targets under electrostatic acceleration. The most recent results by Naranjo et al. [11], [12], [13] and recently Celani [14] also suggest that a

neutron flux from pyroelectric crystals can exceed the natural background neutron radiation by 400 times.
Based on the above proposal we believe that it is possible to use transient electric pulses of low energy and high power (due to their transient character) in devices containing Deuterium absorbing metal like Paladium to search for fusion events. Such a low energy reaction scenario can be characterized as a “Bipolar fusion” due to the short time extremely high transient near field effects of dipoles.

4. Conclusions

We proposed an alternative explanation of the wire fragmentation phenomenon based on purely electromagnetic phenomena without the need to introduce any modification to the existing force laws compatible with Maxwell equations. Further experimental results are necessary in order to explore the validity of our approximations. We also suggest the phenomena in this region may prove of major importance if high voltage electrical pulse devices (and proper fast switches) are to be combined with Deuterium absorbing metals or metals embedded in a Deuterium atmosphere in which case certain nuclear phenomena may occur with possible applications in fusion research.

5. References

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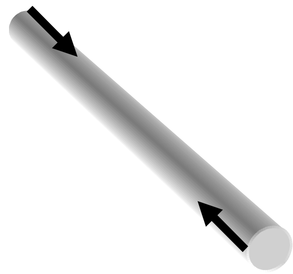

Fig. 1 Schematic representation of the oppositely oriented instantaneous dipoles on the wire volume

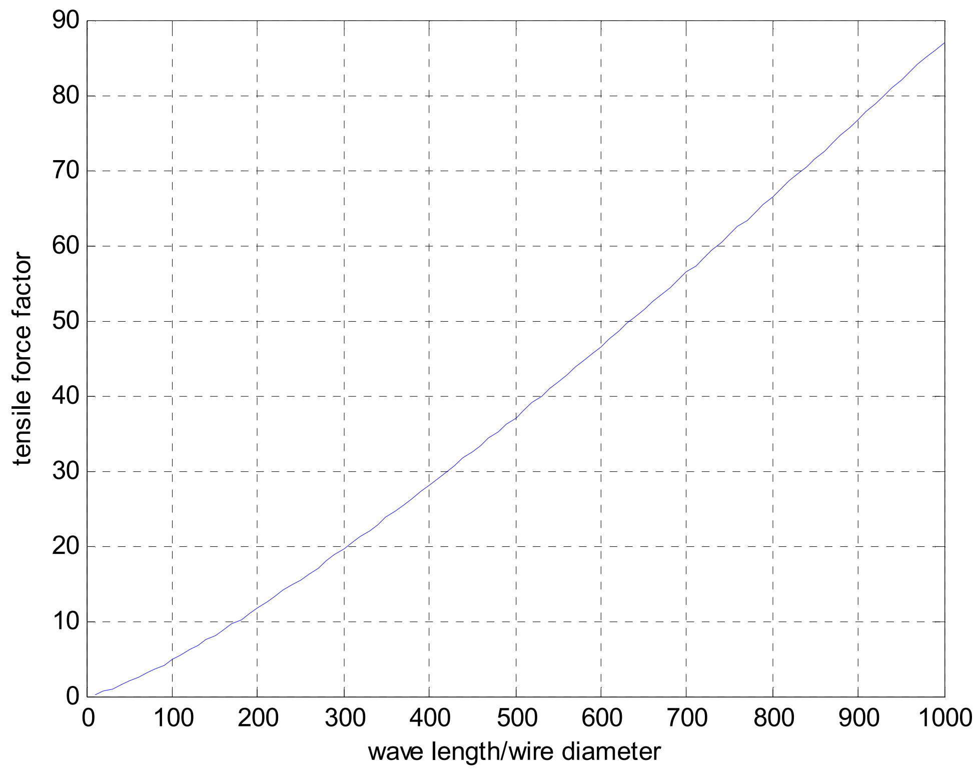

Fig. 2 Results from numerical evaluation of the force integral (12).