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Magneto-acoustic resonance modes in Coler-type apparatus

Abstract

Coler's original electro-magnetic apparatus was claimed to provide an unexplained source of energy. An apparatus able to supply unlimited power output would have clear potential uses in deep-space missions. The equipment consists of a unique arrangement of electro-magnetic excitation coils and ferromagnetic cores, each having a length much larger than the core diameter. Recent investigations concerning this apparatus have explained certain phenomena by hypothesizing that there exist longitudinal acoustic resonant modes within the magnetic cores used. The large length/diameter ratio allows consideration of modes with wave-vector parallel to the principal axis independently of possible modes in other directions that are not excited by the excitation coil arrangement. However, differences in the amplitudes of the observed modes were left unexplained. In the present paper, it is shown that the hypothesis of exciting longitudinal acoustic modes will explain the observed differences in resonance amplitudes when the lengths of the excitation and pick-up coils on the magnetic core are considered. Some modes are excited more than others according to the physical overlap of each normal mode with the excitation and pick-up coils. As a result, the coils can be designed to maximize the resonant amplitudes, thereby optimizing the operation of the apparatus.

Keywords

Acoustic resonance; Coler; Excitation; Harmonics; Kohler; Magnetism; Magnetostriction; Multimode; Standing waves.

INTRODUCTION

The Coler-type electro-magnetic apparatus was developed around 70 years ago in the 1940s and was described in a secret (and subsequently declassified) report prepared by the U.K. British Intelligence Objectives Sub-Committee[1] that appears to represent the first occasion that its main details were freely published. The apparatus has recently been re-examined in further detail by Ludwig[2]. Coler's original apparatus consisted of a special hexagonal arrangement of coils and magnets, with additional sliding and/or rotating electrical and magnetic parts, the whole allegedly able to produce or generate electrical power without corresponding chemical or mechanical power input. Recent attempts at explaining aspects of its operation suppose that magnetic excitation sets up longitudinal acoustic waves within the magnetic cores of the Coler apparatus that are excited through magnetostriction. This explains a number of the resonant phenomena associated with its operation[3]. Left unexplained was the apparently random and complicated pattern of amplitudes obtained when each of the magneto-acoustic resonant modes was excited individually (as in recording a spectrum response plot). In fact, Ludwig[3] states: "No solid explanation for this structure has been found so far." In the present paper, it is shown that the amplitude structure of these resonances can be interpreted as a direct result of non-ideal excitation and signal retrieval by the magnetic coils surrounding each magnetic core.

Note that there is no comment herein on the original claims that the apparatus furnishes an unexplained source of energy. However, Ludwig[3] explains that there were apparently credible witnesses for an experimental proof of principle of a device working with permanent magnets and no input power. As a result, Ludwig[3] speculates that the excess power produced over the input power might be explained as a result of electron magnetism resulting from a relativistic quantum effect with corrections due to the exchange of energy with the zero-point energy (ZPE) quantum fluctuations. Ludwig[3] suggests that Coler may therefore have discovered a way to covert ZPE into usable energy. If so, permanent ferromagnets (with high remanence) could optimize the effect because of the giant exchange energy within a ferromagnet arising from a collective electron phenomenon[3]. At the present time it appears that this is unproven speculation and, of course, violates the principle of conservation of energy stated in its usual form.

MODEL OF MAGNETO-ACOUSTIC RESONANCE IN A COLER-TYPE MAGNETIC CORE

Each magnetic core in the Coler apparatus is a straight circular cylinder of length L. Its diameter is immaterial here, except that the length is much greater so that well-defined one-dimensional vibrational modes may be assumed. Wound over it is a small electric coil used to excite the magnetic field, consisting of a number of turns of thin wire located between $x = p$ and $x = q$. In normal operation, a sinewave electrical signal is connected to the excitation coil. A diagram of this apparatus is shown in Figure 1 and photographs of the equipment used by Ludwig[3] are shown in Figure 2.

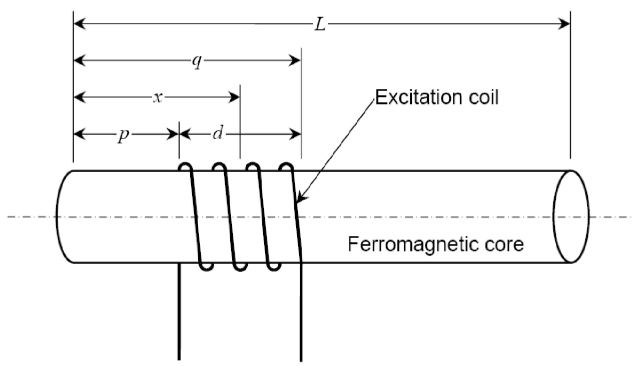


Figure 1 : Basic layout of one magnetic core and excitation coil in the Coler-type apparatus.

Magnetostriction (coupling of magnetization to mechanical strain) sets up acoustic vibrations in the magnetic core, which behaves as a simple longitudinal acoustic resonator. The ends of the cores are unclamped, so that a commonplace analog is an organ pipe un-stopped at both ends. It has been established that the resonance modes observed are consistent with assuming that the usual resonance condition is satisfied,

$$2L = n\lambda \tag{1}$$

(the well-known equation describing an organ-pipe resonance), where n is the mode (or harmonic) number (an integer greater than or equal to unity) and λ is the acoustic wavelength parallel to the rod's cylindrical axis.

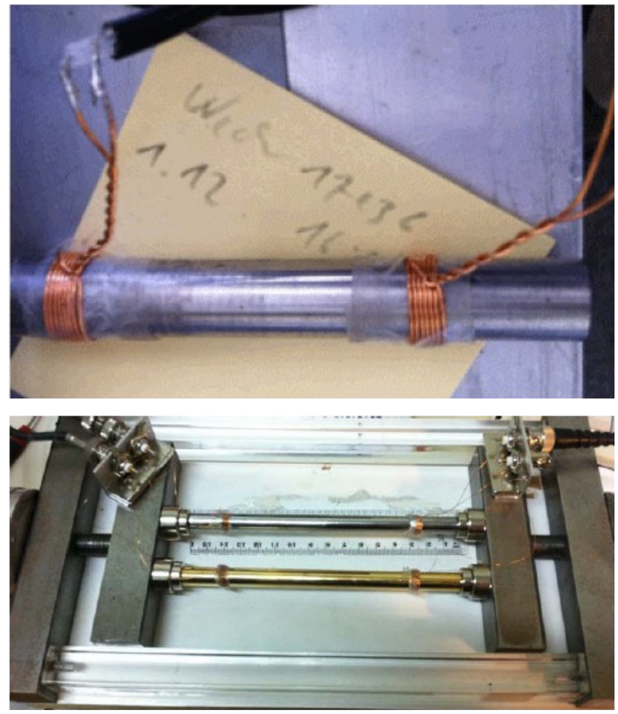


Figure 2 : Photographs of apparatus examined by Ludwig[3]. Reprinted from Physics Procedia, Vol. 38, Ludwig, T., "Tuning Coler magnetic current apparatus with magneto-acoustic resonance," pp. 39–53, Copyright (2012), with permission from Elsevier.

A schematic diagram of a typical acoustic standing-wave mode is shown in Figure 3, showing the longitudinal mode for $n = 3$. Evidently, n may be informally interpreted as being equal to the number of nodes, or one fewer than the number of anti-nodes, in this normal-mode vibration pattern. Because the length is much larger than the rod diameter, modes having a wave-vector transverse to the rod's cylindrical axis are unimportant in the present context. The analysis of the present paper would be unchanged if the important modes were instead *transverse* modes still having their wave-vector parallel to the rod's cylindrical axis.

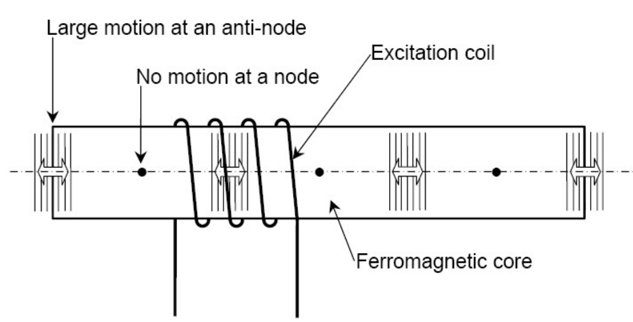


Figure 3 : Schematic diagram of longitudinal acoustic modes in a long rod. Since the ends are not constrained, there are vibrational anti-nodes at both ends, as for an unstopped organ pipe.

In his recent analysis, Ludwig[3] reported on the resonant modes of the apparatus, as measured by a pick-up coil. The pick-up coil was similar to the excitation coil but placed at a different point on the rod, and was connected to a lock-in amplifier. Ludwig[3] found strong resonances coincident with some of the modes predicted by Equation (1). Left unexplained in his plot of the excitation response amplitude was the variation in excitation response as a function of frequency or mode number, and why some of the resonances predicted by Equation (1) were not in fact observed.

It is hypothesized here that the variation of excitation efficacy is a direct result of the non-ideal excitation mechanism used in the reproduced Coler apparatus. Instead of point-source excitation, the excitation coil has a non-zero length from $x = p$ to $x = q$ on the magnetic core. Therefore, rather than equal excitation of each possible mode, some modes will not be excited at all while others will be favored.

As a simple example, if the excitation coil covers the entire left half of the magnetic core, it will certainly excite the fundamental mode ($n = 1$ and $\lambda = 2L$). However, the fourth harmonic, at four times the frequency ($n = 4$ and $\lambda = L/2$), has in the left half of the magnetic core exactly one full wavelength with equal positive and negative excursions, and this harmonic will not be excited at all by this half-length excitation coil.

In general, to evaluate the response amplitude A of the magnetic core excited in the range $p < x < q$, we evaluate in arbitrary units the overlap integral between the exciting coil winding and each fundamental excited mode:

$$A = \frac{1}{q-p}\int_p^q \sin\left(\frac{2\pi x}{\lambda}\right)\mathrm{d}x = \frac{1}{q-p}\int_p^q \sin\left(\frac{n\pi x}{L}\right)\mathrm{d}x \ . \quad (2)$$

where the magnetic force applied to the core is 90° out of phase with the material velocity. For point-source excitation, $q = p$ and then it is required that A is both finite and non-zero unless $\sin(2\pi p/\lambda) = 0$, so normalization by $(q - p)$ is included because the excitation energy will be distributed evenly within the interval $(p..q)$. The integration is trivial and gives

$$A = \frac{1}{q-p}\left[-\frac{L}{n\pi}\cos\left(\frac{n\pi x}{L}\right)\right]_p^q = \frac{L}{n\pi(q-p)}\left[\cos\left(\frac{n\pi p}{L}\right) - \cos\left(\frac{n\pi q}{L}\right)\right]. \quad (3)$$

The well-known factor formula for the difference of two cosines gives

$$A = -\frac{2L}{n\pi(q-p)}\sin\left(\frac{n\pi(p+q)}{2L}\right)\cdot\sin\left(\frac{n\pi(p-q)}{2L}\right), \quad (4)$$

and so the response measured without regard to phase (polarity) will be

$$A = \frac{2L}{n\pi d}\left|\sin\left(\frac{n\pi x}{L}\right)\cdot\sin\left(\frac{n\pi d}{2L}\right)\right|, \quad (5)$$

where $d = q - p$ is the length of the excitation coil, and $x = (p + q)/2$ is the mid-point position of the excitation coil.

COMPARISON WITH EXPERIMENTAL RESULTS

In the recently reported experiments[3], a separate coil was used for signal retrieval, outwardly similar to the excitation coil. Through reciprocity, the response of this retrieval coil will vary in a manner similar to that of the excitation coil, so that using the subscripts e and r for excitation and retrieval respectively, the final response amplitude obtained is (again, in arbitrary units so that multiplicative constants may be disregarded):

$$A = \frac{4L^2}{n^2\pi^2 d_e d_r}\left|\sin\left(\frac{n\pi x_e}{L}\right)\cdot\sin\left(\frac{n\pi d_e}{2L}\right)\cdot\sin\left(\frac{n\pi x_r}{L}\right)\cdot\sin\left(\frac{n\pi d_r}{2L}\right)\right|. \quad (6)$$

As shown in Figure 2, a number of magnetic cores and coil arrangements were used in Ludwig's experiments[3]. Figure 4 (a) shows the frequency response reported by Ludwig[3], and for comparison Figure 4 (b) shows the values produced by Equation (6) (normalized for convenience numerically to the maximum excitation in the range plotted, and with axes adjusted for easy comparison with the experimental results). A generalized reduced gradient (GRG2) nonlinear optimization code was used to optimize the parameters x_e, d_e, x_r, and d_r while keeping L constant, by minimizing the total squared deviation of the simulation from the experimental resonant amplitudes summed over all the harmonic numbers for which there is data, giving the parameter values listed in Figure 4 that illustrate the best agreement with the experiment. All lengths determined are given in arbitrary units as only their ratios appear in Equation (6) and so from the frequency response alone absolute values cannot be obtained.

If both ends of the magnetic core are clamped, the boundary conditions will be different as there will be a node at each end rather than an anti-node. In this case, the overlap integral of Equation (2) will be:

$$A = \frac{1}{q-p}\int_p^q \cos\left(\frac{2\pi x}{\lambda}\right)\mathrm{d}x = \frac{1}{q-p}\int_p^q \cos\left(\frac{n\pi x}{L}\right)\mathrm{d}x \quad (7)$$

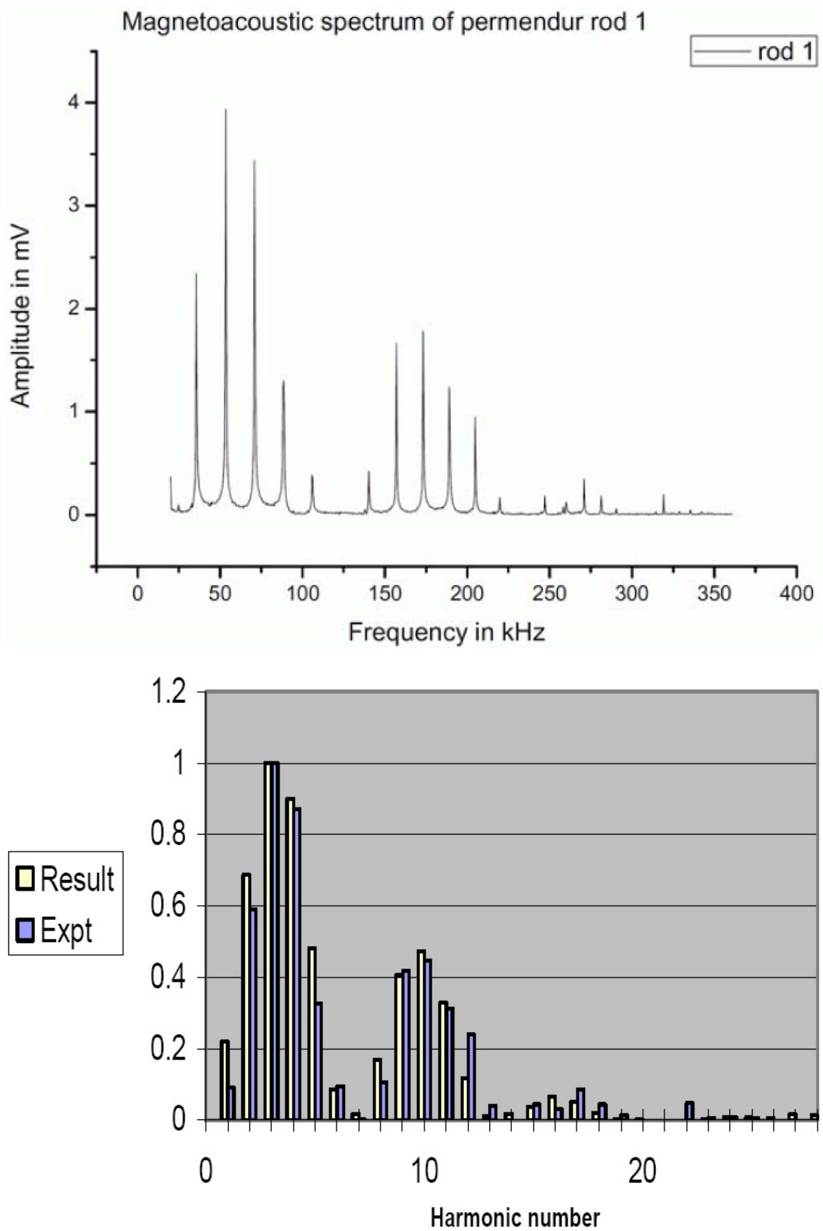
so that:

$$A = \frac{L}{n\pi(q-p)}\left[\sin\left(\frac{n\pi q}{L}\right) - \sin\left(\frac{n\pi p}{L}\right)\right]. \quad (8)$$

Then, using the algebraic result for the difference of two sines gives, for one coil:

$$A = \frac{2L}{n\pi d}\left|\cos\left(\frac{n\pi x}{L}\right)\cdot\sin\left(\frac{n\pi d}{2L}\right)\right|. \quad (9)$$

For an excitation-pick-up coil pair the overall amplitude response in this case will be:



(a)

(b)

Figure 4 : (a) Experimental frequency response of the magnetic core/excitation coil system as reported by Ludwig[3], reprinted from Physics Procedia, Vol. 38, Ludwig, T., "Tuning Coler magnetic current apparatus with magneto-acoustic resonance," pp. 39–53, Copyright (2012), with permission from Elsevier; (b) normalized result from the present analytic simulation, Equation (6), using the parameters x_e = 2.80, d_e = 1.75, L = 18.3, x_r = 15.71, d_r = 1.75 (all in arbitrary units), compared with experimental data[3] transcribed from the graph above (a).

$$A = \frac{4L^2}{n^2\pi^2 d_e d_r}\left|\cos\left(\frac{n\pi x_e}{L}\right)\cdot\sin\left(\frac{n\pi d_e}{2L}\right)\cdot\cos\left(\frac{n\pi x_r}{L}\right)\cdot\sin\left(\frac{n\pi d_r}{2L}\right)\right|. \quad (10)$$

If one end of the core is free and the other is clamped, then the resonance condition of Equation (1) is modified to:

$$2L = \left(n - \tfrac{1}{2}\right)\lambda \quad (11)$$

and either Equation (6) or Equation (10) applies respectively with n replaced by $\left(n - \tfrac{1}{2}\right)$. None of these latter cases, however, corresponds to the arrangement reported by Ludwig[3].

DISCUSSION

As shown in Figure 4 (b), clearly the agreement between the experiment and the simulation is excellent, and the present simulation adequately describes the previously observed[3] variations in resonance response amplitude. Deviations of the experimental results from the present simulation can probably be ascribed to rapid sweeping of the frequency source of the response analyzer (giving uncertain resonant amplitudes) and to non-uniform winding of the excitation coil, which is apparent in the photographs of Figure 2 as non-equally-spaced winding separations. Since these are not well-controlled in this implementation of the Coler apparatus it seems difficult to model these exactly, although a future investigation may wish to do so using better-controlled and characterized windings. The fact that the excitation coil is made up of individual turns rather than a continuous current-sheet will also have the effect of introducing a deviation from the ideal response, although only when the turn separation becomes a significant fraction of d.

The values of d_e and d_r found by the optimization shown in Figure 4 (b) may not be the actual physical lengths of the two coils. This is because the influence of the coils is spread out from their physical location by the channeling of the magnetic field within the ferromagnetic core, and it also depends on the details of how the magnetostriction converts between mechanical strain and magnetization. The values of d_e and d_r found will actually be the respective effective magnetic lengths of the coils, renormalized by the effects of the magnetic core. These will normally be rather larger than the respective physical lengths.

To maximize the magnetoacoustic response at a particular harmonic n, it is necessary to maximize the values of the two factors on the right-hand side of Equation (5) or Equation (9). This will be achieved when

$$\frac{\left(n-\frac{1}{2}D\right)\pi x}{L}=\frac{1}{2}\pi F+m\pi \quad \text{and} \quad \frac{\left(n-\frac{1}{2}D\right)\pi d}{2L}=\frac{1}{2}\pi+l\pi \quad (12)$$

simultaneously, where l and m are arbitrary integers greater than or equal to zero, D is a parameter equal to unity for different boundary conditions at each end of the core or zero for identical boundary conditions at each end of the core, and F is a parameter equal to unity for a free end at $x = 0$ or zero for a clamped end at $x = 0$. (For the arrangement reported by Ludwig[3], $D = 0$ and $F = 1$.) Equation (12) may be rewritten in simplest form to give the ideal positions and lengths of the coils as:

$$x=L\frac{2m+F}{2n-D} \quad \text{and} \quad d=2L\frac{2l+1}{2n-D}. \quad (13)$$

To obtain the largest possible resonance response amplitude, from Equations (5), (6), (9) and (10) the lowest feasible value of n should be chosen.

CONCLUSION

The acoustic resonance of the magnetic cores in the Coler apparatus is a longitudinal acoustic resonance similar to that of a stopped or un-stopped organ pipe, depending on the core boundary conditions. The observed non-ideal response spectrum is a result of non-ideal excitation and signal retrieval. Practical excitation and signal pick-up using coils of a non-zero length placed at non-midpoint positions along the core results in an apparently complicated excitation spectrum that nevertheless has a form explicable when analyzed correctly and plotted to show the excellent agreement between the results from the hypothesis and those from the experiment. Arising from the analysis, the effective lengths and the positions of the excitation and pick-up coils used in obtaining the prior experimental results can be determined in arbitrary units. In future designs of this apparatus the lengths and positions of the excitation and pick-up coils need to be correctly fixed for optimum performance at the resonance frequencies envisaged. Uneven winding of the coils introduces minor secondary effects in the amplitude structure, which should be mitigated by careful and precise coil-winding using fine wire.

NOMENCLATURE

A = amplitude (arbitrary units)
d = length of excitation coil (m)
D = 1 for different boundary conditions or 0 for identical boundary conditions at each end of the core
e = subscript denoting excitation
F = 1 for free end at $x = 0$, or 0 for clamped end at $x = 0$
L = length of magnetic core (m)
l = integer, zero or greater
m = integer, zero or greater
n = integer mode number (dimensionless)
p = end location of excitation coil (m)
q = end location of excitation coil (m)
r = subscript denoting retrieval
x = coordinate and midpoint of excitation coil (m)
λ = acoustic wavelength (m)

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