THEORY AND APPLICATIONS OF THE MACROSCOPIC QUANTIZATION EFFECT IN NONLINEARLY-COUPLED VIBRATING SYSTEMS

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ABSTRACT

Among the most fruitful areas for research and application of vibrational processes today is a special type of nonlinear interaction between oscillating systems, known as argumental coupling, and the emergence of discrete, "quantized" dynamic regimes in systems of argumentally-coupled oscillators, known as the Macroscopic Quantization Effect (MQE). Many years' work in this area has led to the development of new technologies having potentially enormous economic benefits. These technologies include a highly-efficient nonlinear vibrational process for atomizing liquids into submicron-sized droplets, which opens the way toward drastically reducing energy requirements for evaporative cooling and refrigeration, as well as desalination of sea water. Closely related is a new method for producing highly-stable emulsions, with application to the production of synthetic fuels. The present paper summarizes essential features of argumental interactions and the theory and experimental demonstration of the Macroscopic Quantization Effect, and describes the basic principle behind the new atomization technology.

1 INTRODUCTION

Phenomena involving nonlinear interactions between oscillating systems have been studied for a long time, but their far-reaching implications for science and technology are only gradually being realized. Among the most promising areas for research and application is a special type of nonlinear interaction between oscillating systems, known as *argumental coupling,* and the emergence of discrete, "quantized" dynamic regimes in systems of argumentally-coupled oscillators – the so-called *Macroscopic Quantization Effect (MQE*) – having no equivalent in the classical theory of oscillations. Recent work in this area has led to new technologies having potentially enormous economic impacts, one of which we shall describe here.

2 THE MACROSCOPIC QUANTIZATION EFFECT (MQE)

Argumental interactions and the MQE were first discovered by Danil and Yakov Doubochinski in 1968, and were the subject of extensive experimental and mathematical investigations [1-5]. The classical example is the so-called argumental pendulum (see Figure 1): A low-friction pendulum with a natural frequency ω in range 0,5 - 1Hz and a small permanent magnet affixed to its end, interacts with the magnetic field of a solenoid located under the pendulum's equilibrium position and fed by alternating current of frequency ν between 30 and 1000 Hz. When released from any position, the pendulum's motion evolves into a stable, very nearly periodic oscillation, whose amplitude belongs to a *discrete set of values*. In each of these "quantized" regimes the pendulum oscillates with a frequency near its own undisturbed frequency, compensating its frictional losses by energy drawn from its interaction with the alternating field of the solenoid.

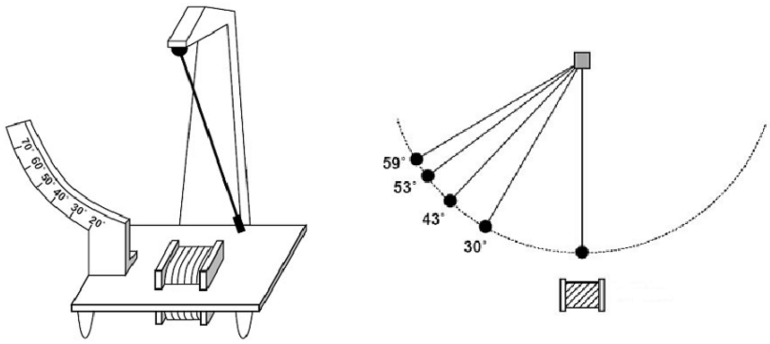

Figure 1. The argumental pendulum and its stable amplitudes (for ω = 0.5 Hz, ν = 50 Hz)

A precondition for this "quantization" phenomenon is the strong *spatial inhomogeneity* of the external field, permitting the pendulum to regulate its exchange of energy with the field by small advances and delays in the moment it enters the narrow "interaction zone", relative to the phase of the solenoid current. The term, "argument interaction", originally referring to the presence of the pendulum angle in the function defining the external force, came to be applied to a whole class of coupled oscillators whose energy exchanges are regulated by phase-frequency-amplitude fluctuations, while each participating oscillator operates at very nearly its own proper frequency.

We now briefly indicate the origin of the "quantized" spectrum of stable regimes in the argumental pendulum and similar systems. Represent the family of free motions of the pendulum (or similar mechanical oscillator) by a generalized coordinate function $X = X(A, \omega, \phi, t)$, such that for each fixed value of the triple (A, ω, ϕ), X is a periodic function in t with frequency ω, amplitude A, and phase factor ϕ. In the simplest relevant cases, the interaction with an external field of frequency ν (ν >> ω) can be described by the differential equation

$$X'' + 2\beta X' + g(X) = f(X)\cos(\nu t) \tag{1}$$

where f(X) expresses the spatial dependency of the interaction with the field. For any *fixed* values of A, ω, ϕ, the function f(X) is a periodic function of t with frequency ω, so that the right side of equation (1) can be expanded in a complex Fourier series:

$$\begin{aligned} f(X)\cos(\nu t) &= (\Sigma\, c_n(A, \omega, \phi)\, e^{in\omega t}) \cos(\nu t) = ½\, \Sigma\, c_n(A, \omega, \phi)\, e^{in\omega} [e^{i\nu t} + e^{-i\nu t}] \\ &= ½\, \Sigma\, c_n(A, \omega, \phi)\, e^{i(n\omega + \nu)t} + ½\, \Sigma\, c_n(A, \omega, \phi)\, e^{i(n\omega - \nu)t}. \end{aligned} \tag{2}$$

From this we can see that in the special case when ν = Nω for some whole number N, the Fourier series for the right-hand side of equation (1) will contain the term

$$[\, c_{1-N}(A, \omega, \phi) + c_{N+1}(A, \omega, \phi)\,]\, e^{i\omega t} \tag{3}$$

whose frequency coincides with that of the oscillator itself. This opens the possibility for a *special sort of resonant energy transfer from the high-frequency field to the low-frequency oscillator*. On account of the pendulum's amplitude-frequency dependence (anisochronicity), the condition ν = Nω translates into a discrete set of amplitudes at which this energy transfer can occur.

To go beyond these qualitative remarks it is necessary to take into account the time-dependency of the values of A, ω and ϕ, which fluctuate slowly around certain average values, and which provide the regulatory element permitting stable, quasi-stationary oscillatory regimes to be maintained. Analysis leads to a complicated set of equations involving the coefficient functions. Applying the method of Krylov-Bogoliubov-Mitropolski, we can demonstrate the existence of quasi-stationary regimes corresponding to a discrete series of average values of (A, ω, ϕ), and account for the other main characteristics of argumentally-coupled systems. For details of the theory of argumental oscillations and the MQE we refer the reader to the technical literature [1-5]. The present authors emphasize the ability of argumental couplings to generate entire hierarchies of stable dynamic regimes, each of which can be regarded as a distinct physical object in its own right [6].

Theoretical and experimental studies have shown that a single high-frequency source can feed not just one, but a large number of different argumental oscillators at the same time, each operating near its own proper frequency and each in any one of a "quantized" array of modes. This is a special case of a more general principle called "*multiresonance*": the simultaneous coupling of ensembles of oscillating systems, in a self-organizing and self-regulating manner, across an orders-or-magnitude-wide range of frequencies. This property of argumental couplings provides an enormous scope for technological applications [7], of which we shall now briefly describe one example.

3 THE ATOMIZING REACTOR

In a patented "atomizing reactor" [7,8] a pulsating flow of water is injected into a chamber at right angles to a flow of air arriving from a compressor through a second tube, and pulsated with much higher-frequency components. In current prototypes the air pulses are shaped as delta functions, and hydrodynamic processes are used to prepare the water in a heterogeneous vibrational state prior to its injection. At the point of intersection with the pulsed air flow, the water stream breaks up into a cloud of droplets of different sizes, each vibrating with its own frequency. Multiresonant argumental interactions with the acoustical field cause droplets to pick up energy and explode into smaller droplets, in turn adding new high-frequency components to the acoustical field. The result is a cascade-like process producing an outlet mist of droplets with diameters less than 1 micron. The atomizing reactor is many times more energy-efficient than conventional atomization methods producing comparable droplet sizes. The performance and operating parameters of prototype devices have been measured and certified by Bureau VERITAS in France as well as the French industrial laboratory LAMI / ENPC-LCPC. Of particular interest is the extremely powerful cooling effect achieved by the atomizing reactor, which is the combined result of the nearly instantaneous evaporation of the submicron droplets upon exit from the reactor, together with the surprising fact – revealed by laboratory measurements –, that the atomization process itself consumes a significant portion of the thermal energy of the air and water entering the system. Projections by the AREVA Technical Center indicate that evaporative cooling systems based on the atomizing reactor, when fully optimized, could achieve Coefficients of Performance (COPs) *10 times higher than systems utilizing the closed Carnot cycle*, for the same inlet and outlet temperatures [8].

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