Asynchronous excitation of undamped oscillations

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The assumption that oscillations maintained by an external harmonic force always assume the frequency of this force or a multiple of this frequency is widely used in the theory and practice of mechanical oscillations. Yet inertial, thermal, and other effects, frequently not taken into account, introduce time shifts between the driving force and the dynamic functions of the oscillations, and can lead to an asynchronous excitation of undamped oscillations.

The delay effect, which is used with tremendous success in microwave electronics, has not yet found application as a operating principle in electromechanical systems. We have developed a number of devices in which definitely prescribed actions applied to oscillations lead to a periodic contribution of energy from an external harmonic source and makes possible generation, amplification, or conversion of oscillations[1]. The oscillatory processes take place at the natural frequency of the oscillations in a damped system with one degree of freedom, acted upon by a harmonically-varying force having a frequency that is not resonant, nor multiple, and in general not even commensurate with the natural frequency. The proposed mechanism permits realization of a self-regulating energy contribution, i.e., it can be used as a mechanism for maintaining undamped oscillations.

We started with the following hypothetical experiment. Let an oscillating electric charge cross during part of its path a parallel-plate capacitor with absolutely permeable electrodes (Fig. 1a), to which an alternating voltage is applied (the time required by the charge to negotiate the gap is of the order of the period of this alternating voltage).

If the amplitude of the field in the capacitor gap reaches a high enough value, then a change in the flight time should occur in the presence of a light charge. Let the time of flight unperturbed by the field be $\tau_0 = 3T/4$ (T is the period of the alternating field). At an initial entry phase $\varphi_1 = 0$ (Fig. 1b), acceleration will take place during the initial half of the period, followed by deceleration. Therefore the real flight time τ_1 is smaller than the unperturbed flight time, and a positive energy contribution proportional to the shaded area in Fig. 1b is produced.

If the initial phase is $\varphi_2 = \pi$, the time of flight is larger than at $\varphi_1 = 0$, and this leads to a large deceleration, i.e., to a negative energy contribution (Fig. 1c).

Comparison of these two swings leads to the conclusion that the resultant energy contribution is positive. If the natural oscillation frequencies of the charge and of the alternating field are not commensurate, all initial entry phases can be regarded as equally probable, and we can reason analogously for all other pairwise-taken flights with initial phases φ and $\varphi + \pi$, so that a predominant energy contribution results (Figs. 1d, 1e).

For any entry phase, the time of flight τ_f can be calculated (if the velocity varies linearly) from the formula

$$\tau_f = \frac{d}{v_0 + \Delta v_0 \cos\varphi_f} = \frac{\tau_0}{1 + (\Delta v/v_0)\cos\varphi_f} = \tau_0(1 - a\cos\varphi_f),$$

where d is the length of the interaction region (width of the capacitor gap), v_0 is the unperturbed flight velocity ($v_0 = d/\tau_0$), and φ_f is the entry phase. It is assumed that $a = \Delta v/v_0$ is small.

It can thus be stated that when the frequency of the oscillating system is not commensurate with that of the alternating external force, a resultant positive energy contribution (averaged over a number of oscillations) is possible if the system alters the time of flight through the interaction space sufficiently strongly.

All the arguments cited above can be repeated for a time of flight equal to T/4, in which case we have predominant deceleration (generator regime).

Understandably, such interactions are possible not only in the particular system considered, but also in any

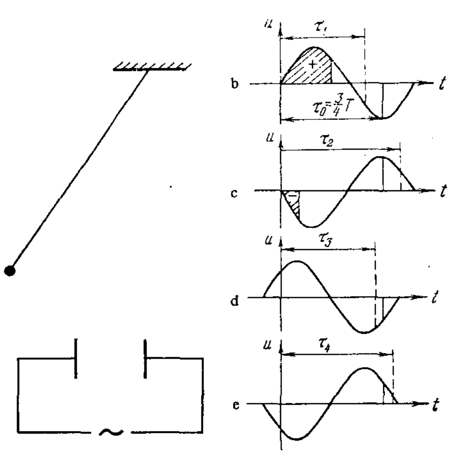

FIG. 1.

oscillatory system with a short interaction space in which a harmonic force acts.

The change of the time of flight through the interaction region is widely used in electronics. When it comes to macroscopic masses, it is doubtful whether a sufficient change in the time of flight is realizable, and so consequently whether this change can be used as a basic principle for a new class of oscillations (which we call argument oscillations).

To prove the feasibility of altering the time of flight of a current-carrying conductor or of a charge (electric or magnetic) through an interaction space with an alternating field and the feasibility of maintaining undamped oscillations (at practically the natural frequency) under the influence of an external force having a nonresonant frequency, we constructed a setup that operates in a large interval of flight times.

A block diagram of the setup is shown in Fig. 2. Pendulum 1 in suspension 2 can move in one plane. Mounted on the pendulum is a magnet 3, which interacts with coil 4 wound on a ferrite U-shaped core 5. A ferrite core is necessary to keep the interaction space practically constant as the current is varied. A magnetic latch 6 makes it possible to hold up the pendulum with the aid of a ferrite 7 attached to the pendulum shaft. A power-control unit 16 (its diagram is shown in Figs. 3–4) makes it possible to release the pendulum at a definite phase of the source 25 that triggers the pulse generator 18, the delay of which determines the instant of operation of the power unit 16.

To hold up the pendulum for a longer time (prior to its release), a block 17 is located between blocks 16 and 18. Its diagram is also shown in Fig. 3. Block 17 generates one pulse for every hundred triggering pulses of block 18. The magnetic latch can be moved along a graduated scale 8, thereby varying the speed at which the pendulum enters the interaction space.

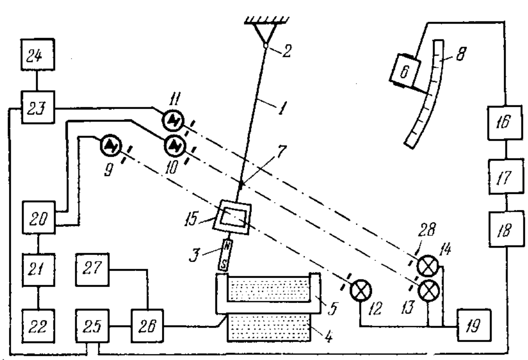

FIG. 2.

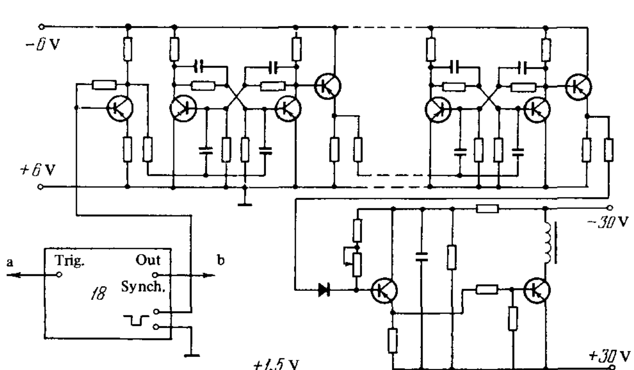

FIG. 3.

Measurement of the time of flight and determination of the time of entry into the interaction space are effected by pickups 9–11; these are photodiodes illuminated by lamps 12–14. When the measuring frame 15 moves, it crosses the light beam from the source, and the signal from the corresponding pickup is fed to block 20 for amplification and shaping, and then to digital frequency meter 21, from which the results can be read.

Measurement of the time and speed of flight reduces to measurement of the time between the pulses produced by one of the photodiodes when the light beam is crossed by the edges of the measuring frame 15.

The photodiode 9 is so mounted that the edge of the measuring frame crosses the light beam at the instant of entry into the interaction space, while the second edge produces a pulse at the instant of exit from the interaction space. Thus, measurement of the time between the pulses produced when the light beam is crossed by the frame determines the time of flight uniquely. Knowing the frame dimensions, we can determine the speed of the pendulum.

Photodiode 10 can be used to measure the speed of the pendulum as it leaves the interaction space, in analogy with the procedure with photodiode 9. Photodiode 11 generates a signal when the light beam is crossed by the pendulum axis. This signal is fed to oscilloscope 24 through block 23. The latter switches this signal with the supply voltage. Thus, besides obtaining numerical data, it is possible to observe visually the phase of entry of the magnetic charge into the interaction space.

For the experiment to be accurately performed, the moving system should have low friction losses (use of bearings) and should be quite rigid over an appreciable fraction of its length. This is necessary to eliminate vibrations produced in the working plane during the interaction of the permanent magnet with the alternating field of the coil (such vibrations affect adversely the experimental results), and to get rid of vibrations in the plane perpendicular to the oscillation plane, since these give rise to appreciable errors. Since displacements in the non-working plane did take place, it was necessary to use a special field configuration. In addition, the interaction region had to be appreciable, this being the only way to produce a change in velocity and hence a change in the time of interaction between the pendulum and the external harmonic force. This change of the interaction time during the oscillatory regime of the setup causes the energy contribution from the external force to the oscillatory process.

If the energy imparted to the pendulum in the interaction space is negligible in comparison with the kinetic energy of the pendulum, then the interaction time will not change in this space. The principal condition for obtaining a sufficient change in the pendulum velocity under the influence of the external field, besides sufficient induction of the permanent magnet and sufficient current amplitude, is that the pendulum mass be small.

A pendulum 730 mm long was made of a light wooden bar with 5×5 mm square cross section. A metallic shaft was securely fastened on one end of the pendulum, and on the other a permanent magnet measuring $9 \times 9 \times 20$ mm. A measuring frame of sheet bakelite 2 mm thick was mounted 5 mm away from the magnet.

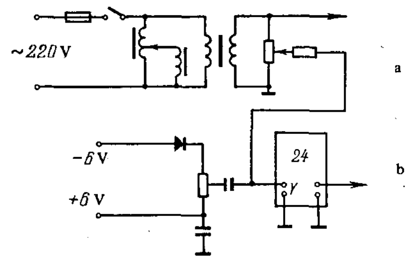

FIG. 4.

The distance between the vertical sides of the frame was 46 mm, the sides themselves being 1.8 mm wide. The apparatus was fed from the ac power line (50 Hz) through a single power supply 25. The natural frequency of the pendulum oscillations was 0.55 Hz.

The experimental setup made it possible to measure the time of flight as a function of the entry phase, the entry and exit speeds of the pendulum, the period of the pendulum, and other quantities. The results were reproducible with sufficient accuracy. The apparatus has yielded a reliable confirmation of both the feasibility of changing the time of flight and the presence of stable oscillations of the damped oscillatory system with one degree of freedom. An analysis of the experimental data has confirmed that the stable pendulum oscillations are due precisely to the change of the time of motion of the pendulum in the interaction space.

The conditions for a positive energy contribution are, apparently, the inequalities

$$T/2 < \tau_0 < T, \quad (1)$$

where τ_0 is the time of unperturbed flight through the interaction space and T is the period of the external force.

The conditions for a negative energy contribution are the inequalities

$$0 < \tau_0 < T/2. \quad (2)$$

Formulas (1) and (2) correspond to the time of flight for the fundamental oscillation in the oscillatory and in the generator regimes.

For the non-fundamental oscillations, the time of flight takes on the values

$$\tau = \tau_0 + nT \quad (n = 1, 2, \ldots).$$

The members of the laboratory of the theoretical physics division of the Vladimir State Pedagogical Institute of constructed a number of devices in which argument oscillations and the principle of argument self-oscillations are used[2].

A number of motors operating on argument principle of energy input have several synchronous speeds. An argument motor was constructed with five synchronous rotor speeds (at one and the same frequency and at constant amplitude of the ac supply voltage). The synchronous speed of one of the motors can be changed by changing the size of the interaction region. One feature of argument motors is that the synchronous speeds are practically independent of the supply voltage or of load changes in a wide range. The argument principle was used to construct several models of electromechanical oscillating systems with oscillation amplitudes that stay constant when the supply voltage is varied by a factor of several times ten.

Thus, the experiments predict reliably the feasibility of producing stable oscillations in a damped oscillatory system, provided that the nonresonant external force alters in a prescribed manner the time of interaction or the time of action on the oscillatory system.

The argument mechanism of energy input has the following features:

1) The presence of a number of discrete stable amplitudes.

2) The oscillation amplitudes are independent (in a rather wide range) of the amplitude of the energy source.

3) Discrete oscillation amplitudes can be excited in an oscillating system without friction.

4) The oscillation amplitude is independent of the dissipation in the system (in a wide range).

5) While the individual amplitudes and periods of the oscillations may fluctuate, owing to the statistical nature of the interaction, the averaged values of the amplitudes (and accordingly of the period of the oscillations) exhibit high stability.

[1]L. I. Penner, Ya. B. Duboshinskiĭ, D. B. Duboshinskiĭ, M. I. Kozakov, Dokl. Akad. Nauk SSSR 204, 1065 (1972) [Sov. Phys.-Dokl. 17, 541 (1973)].

[2]Yu. V. Galkin, A. S. Vermel', Ya. B. Duboshinskiĭ, and D. B. Duboshinskiĭ, Inventor's certificate No. 344403 of 19 April 1971. Byull. Izobret. No. 21, 192 (1972); Ya. B. Duboshinskiĭ, A. S. Vermel', D. B. Duboshinskiĭ, and M. I. Kozakov, Inventor's certificate No. 344404, 19 April 1971, Byull. Izobret. No. 21, 193 (1972). Yu. V. Galkin, M. I. Kozakov and A. S. Vermel', Uch. Zap. Vladimirsk. ped. in-ta, ser. Fizika, 40(6), 85 (1972).