Physics of Processes

Introduction

Topics of lectures

1. System, process, force, energy
2. Periodic processes, description, harmonic processes, Fourier's set
3. Mechanical vibrations free, harmonic, linear harmonic oscillator, superposition and polarization of vibrations
4. Damped and forced harmonic oscillator, its energy, applications
5. Folding of oscillations, wave generation and propagation, wave equation, applications
6. Formation of standing waves, standing waves in strings, rods and other objects, energy
7. Alternate electrict current, electromagnetic induction, oscilation circuit
8. Electromagnetic waves, application of results obtained at mechanical waves
9. Introduction to modern physics
10. Nuclear energy - nuclear fission
11. Nuclear energy - nuclear fusion
12. Fundamental changes of systems - grow functions and kinetic equations, survival curves

Literature:

Blackstock, D.T.: Fundamentals of physical acoustics. John Wiley, New York 2000, 542 p.

Crawford, F.S., Jr.: Waves. Berkeley Physics Course, Vol. 3, McGraw-Hill College, New York, 1968

Daniels, F., Alberty, R.A.: Physical Chemistry. J. Wiley & Son, Inc., New York 1987, 944 p.

Halliday, D., Resnick, R., Walker, J.: Fundamentals of Physics, Sixth Edition. Wiley International Edition, John Wiley & Sons, 2001

https://en.wikipedia.org/wiki/Complex_number

Li, Feng-ri; Zhao, Bao-Dong; Su, Gui-lin: A derivation of the generalized Korf growth equation and its application. Journal of Forestry Research 11 (2000), p. 81-88.

Pain, H.J.: The Physics of Vibrations and Waves, John Wiley and Sons Chichester, 2005

Skudrzyk, E.: Simple and Complex Vibrating Systems. The Pennsylvania State University Press, University Park 1969, 500 p.

Wiley, R.B., Stewart, W.E., Lighfoot, E.N.: Transport Phenomena. John Wiley and Sons Chichester, 2002

Yamamoto, H., Haginuma, S. 1984. Estimation of the dynamic Young’s modulus of apple flesh from natural frequency of an intact apple. Report National Food Research Institute, 44, p. 30–35.

Physical systems and their properties

- physical system is a part of the physical universe
- system surroundings – the part of nature which does not belong to the given system
- the behavior of a system is determined by its physical state
- system status is described by status variables and status functions
- the state of the system changes the action or sequence of actions (process)
- parameters of system:
- external - describe the effect of the environment on the system
- internal - characterize only the system
- real systems are simplified into model systems:
- mass point, ideal gas, ideal liquid, etc.

Classical mechanics of space-time

- a significant change of the physical system is the change of the space-time configuration – the motion - which is what mechanics deals with

- classical Newtonian mechanics is based on the idea of force action between material points or bodies (via force fields)

- it is formulated using vectors

- the position vector in the Cartesian coordinate system determines the instantaneous position of a mass point:

$$\vec{r} = r_x \vec{i} + r_y \vec{j} + r_z \vec{k}$$

System of N particles S (N)

- the system of *N* mass points is denoted by the symbol S (*N*)
- instead of the term material point we will use the term particle

- free system - particle motion is not restricted - it can be described by Newton equations:

$$m_i \dot{\vec{v}}_i = \vec{F}_i \,(i = 1,\dots, N)$$

- <u>this applies in the inertial system</u> - where the first Newton's law applies

- <u>but the S (*N*) system is usually bound by bonds</u> (restriction) expressed by equation or inequation

- bilateral (maintaining) bonds

- one-sided (non-maintaining) bonds

- equation $f(\vec{r}_1,\dots,\vec{r}_n;t) = 0$ **characterizes**

- <u>*holonomic*</u> (integrable) tie - in equation only time and coordinates

- can be expressed also by differential equation

System of *N* particles S (*N*)

non-holonomic bonds **(including other components - eg speed)**

reonomic (non-stationary) **- time is explicitly expressed in the bond condition**

scleronomic (stationary) **opposite of reonomic condition**

geometric **- in the binding condition only coordinates, special case of scleronomic conditions**

kinematic **- velocities also occur in bond conditions**

Generalized coordinates for bound particles

- system particles S(N) limited by s holonomic bond conditions:

$$\varphi_j\left(\vec{r}_1,\ldots,\vec{r}_N;t\right)=0;(j=1,\ldots,s)$$

The number of degrees of freedom of the system is $f = 3N - s$

- elimination of s dependent coordinates:

By transforming the original $3N$ coordinates to f new independent generalized coordinates: $q_1, q_2, \ldots, q_f$

- the original coordinates are:

$$x_{ki} = x_{ki}\left(q_1,\ldots,q_f;t\right); \qquad k = 1, 2, 3, \; i = 1, \ldots N$$

- the new generalized coordinates define a point in f-dimensional space

A simple example

One particle whose motion is bound to a circle:

instead of two Cartesian coordinates x_1 and x_2 satisfying the holonomic resp. scleronomic (geometric) bond equation:

$$|\vec{r}|^2 = r^2 = x_1^{\ 2} + x_2^{\ 2}$$

it is enough to use one generalized coordinate φ, with which we express both Cartesian coordinates:

$$x_1 = |\vec{r}|\cos\varphi$$
$$x_2 = |\vec{r}|\sin\varphi$$

Newton's laws of motion

I. *Law of inertia* **- contitutes** **inertial systems**

II. *Law of force* $\dot{\vec{p}}_i = \vec{F}_i$ **- fundamental law of classical mechanics**

III. *Law of action and reaction* **- symmetry of acting forces, basis of dynamic equilibrium**

- the use of NL for bound systems leads to problems:

1. **Equations of motion do not include bonds**
2. **The bond forces are unknown**

- therefore, Newton's mechanics is suitable for the study of free and not of bound systems

- for bound systems it is necessary to use variational principles from analytical mechanics

Introduction to analytical mechanics

Euler-Lagrange equations

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = 0$$

$L = L(q_i(t),t) = T - U$

Lagrange function

T – kinetic energy

U – potential energy

<u>non-conservative systems</u> - potential energy in a generalized sense,

the quantities *T* and *U* can be expressed in arbitrary coordinates,

we do not have to introduce the notion of force or even the bound

conditions to determine the motion of the system!

Introduction to analytical mechanics

Hamilton canonical equations

Conversion of Euler-Lagrange equations to canonical (Hamiltonian) form

(from 2nd order differential equations to 1st order differential equations):

- introduction of generalized momentum

$$p_i \equiv \frac{\partial L}{\partial \dot{q}_i} = p_i(q, \dot{q}, t); \quad i = 1, \dots, f$$

- transition from variables $(q_i, \dot{q}_i)$ **to variables (*q_i*, *p_i*):**

- where:

$$H(q_i, p_i, t) = \sum_{j=1}^{f} p_j \dot{q}_j - L(q_i, \dot{q}_i, t)\Big|_{\dot{q}_i \to p_i}$$

$$\dot{q}_i = \frac{\partial H}{\partial p_i}$$

$$\dot{p}_i = -\frac{\partial H}{\partial q_i}$$

$$\frac{\partial H}{\partial t} = -\frac{\partial L}{\partial t}$$

The function *H*(*q_i*, *p_i*, *t*) is called the Hamiltonian function

- has the dimension of energy,

- if *L* does not depend explicitly on time, ie if $\partial L / \partial t = 0$**, then *H* = const.,**

- in most cases *H* is the same as the total energy of the system: *H* = *T* + *U*