MINISTRY OF EDUCATION OF THE REPUBLIC OF BELARUS
ESTABLISHMENT OF EDUCATION
BREST STATE TECHNICAL UNIVERSITY
DEPARTMENT OF APPLIED MECHANICS

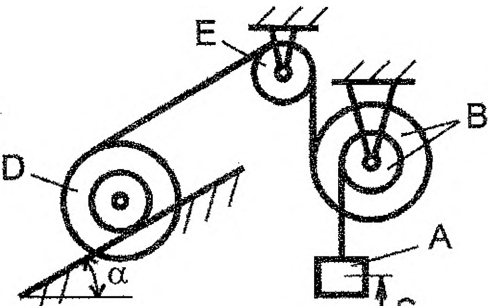
APPLICATION OF THE THEOREM OF CHANGE OF KINETIC ENERGY TO STUDYING OF THE MOVEMENT OF MECHANICAL SYSTEM

TASKS AND METHODICAL INSTRUCTIONS

for performing calculated graphic works on a course

«Theoretical mechanic»

for students of a specialty 1 – 70 02 01 «Industrial and civil engineering»



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The theoretical mechanics is one of the main all-technical disciplines which are the base for studying of special disciplines and training of the qualified engineers of technical specialties. For acquirement of skills of engineering calculations students perform calculated graphic works on the main sections of a course.

The present methodical instructions contain brief theoretical material on the Chapter «The theorem on change of kinetic energy of mechanical system», section «Dynamics», and condition of tasks for performance of calculated graphic works.

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INTRODUCTION

Tasks and methodical instructions correspond to basic curriculum (academic plan) of technical specialties and include short theoretical data, conditions of a task for performance of calculated graphic work and examples of calculations. At defense of calculated graphic work it is necessary to answer the questions connected with its performance and to solve control problems of its subject.

INSTRUCTIONS ON REGISTRATION OF CALCULATED GRAPHIC WORKS

1. Calculated graphic works are performed on standard sheets of the A4 format (210 x 297 mm) with a stamp of 15 mm and the indication of numbering of pages.

2. Registration order: the title page with the indication of option; a task with the indication of basic data and schemes of designs; the text of the decision with necessary explanations and schemes; conclusions; list of literature.

3. Drawings and schemes are carried out with observance of rules of graphics and scales of the standard of university.

4. A text part is carried out according to execution requirements of text documents. Calculations are carried out in a general view, in the received expressions values of the sizes, the numerical result with the indication of dimension are substituted (entering them). The corresponding dimensions of the received values are specified in the answer. All calculations are made in decimal fractions to within the third sign after a comma.

5. All drawings (schemes, schedules, etc.) have to be numbered, designated, mentioned in the text.

1. SHORT THEORETICAL DATA

Kinetic energy is a scalar measure of mechanical motion.

Kinetic energy of a material point is a scalar positive size equal to a half of the mass of a point on a square of its velocity, i.e. $\frac{mV^2}{2}$.

Kinetic energy of mechanical system — the sum of kinetic energies of all material points of this system:

$$T = \frac{m_1V_1^{\ 2}}{2} + \frac{m_2V_2^{\ 2}}{2} + ... + \frac{m_nV_n^{\ 2}}{2} = \sum_{k=1}^{n} \frac{m_kV_k^{\ 2}}{2} \qquad (1)$$

Kinetic energy of the system consisting from ***n*** bodies bound among themselves is equal to the sum of kinetic energies of all bodies of this system:

$$T = T_1 + T_2 + ... + T_n = \sum_{k=1}^{n} T_k. \quad (2)$$

Kinetic energy of a solid at different types of the movement of a solid:

1. Translation motion.

At translation motion of a body:

$$T = \frac{MV^2}{2}. \quad (3)$$

2. Rotation of a body around a fixed axle:

$$T = \frac{I_z \omega^2}{2}. \quad (4)$$

where $I_z = \sum m_k r_k^2$ — moment of inertia of a body about the axle.

3. ***At the plane-parallel motion*** of a body kinetic energy consists of kinetic energy of translation motion of a body with a speed of the center of masses $\frac{MV_C^2}{2}$ and kinetic energy of the rotation motion around the axis passing through the center of masses $\frac{I_{zC}\omega^2}{2}$:

$$T = \frac{MV_C^2}{2} + \frac{I_{zC}\omega^2}{2}. \quad (5)$$

Theorem of change in the kinetic energy of mechanical system

1. The theorem in a differential form.

The differential from kinetic energy of mechanical system is equal to the sum of elementary work done by all the external and internal forces acting on system.

$$dT = dA^e + dA^i. \quad (6)$$

We will divide (6) into dt:

$$\frac{dT}{dt} = \frac{dA^e}{dt} + \frac{dA^i}{dt}, \quad (7)$$

where $\frac{dA^e}{dt} = N^e$ — the power of external forces; $\frac{dA^i}{dt} = N^i$ — power of internal forces. Then:

$$\frac{dT}{dt} = N^e + N^i, \quad (8)$$

2. The theorem in an integral (final) form.

Change in the kinetic energy of mechanical system on some displacement is equal to the sum of work done of the external and internal forces applied to system on the corresponding displacement of points of their application:

$$T_2 - T_1 = \sum_{k=1}^{n} A_k^e + \sum_{k=1}^{n} A_k^i \quad (9)$$

T_2 – kinetic energy of system at $S=S_2$, T_1 - kinetic energy of system at $S=S_1$.

If system moves from a condition of rest, then $T_1 = 0$, $\sum_{k=1}^{n} A_k^i = 0$ — on property of internal forces. Then:

$$T_2 = \sum_{k=1}^{n} A_k^e . \tag{10}$$

2. TASKS TO CALCULATED GRAPHIC WORK

On the schemes given below, options of mechanical systems are given. Bodies of systems can move in the vertical plane under the influence of forces of weight, elastic forces of springs, friction forces (sliding and rolling friction) and the set active forces. Threads are considered as weightless and inextensible, their inclination is identical with an inclination of the corresponding basic planes. Rolling of bodies happens without slipping. All schemes need to be added with a spring of the set rigidity *c* which one end is fixed on a body *1*, and the second fastens to the motionless surface located at some distance before this body.

The condition of system at $t<0$ is a condition of static balance. It is provided with action of forces of weight, friction and spring elastic force. At $t = 0$ body *1* is given the initial velocity of V_0 (as threads don't stretch, the corresponding initial velocity's receive also other bodies of system).

The active force of F^a is applied to a body *1* at $t \geq 0$ and its direction of action matches the direction of displacement of this body specified on schemes $S_1 \leq S \leq S_2$, and the values of force depends on the reached displacement. (S - intermediate position of a trajectory of the displacement of a body *1*; S_1 – initial position of a body *1* at $t=0$; S_2 – final position).

It is required to determine the law of change of velocity of a body *1* depending on its displacement and effort value in the thread linking bodies *1* and *2* by the available data. To define also numerically of the specified values in timepoint when the body *1* passes the set way of S_2.

Explanations to designations and numerical data:

m_1, m_2, m_3, m_4 – the mass of bodies *1-4* expressed through a certain weight m,

R, r – radiuses of circles of wheels (indexes indicate the corresponding body),

i_2, i_3 – radiuses of gyration of the bodies with respect to (w.r.t) axis passing through their centers of masses (if radiuses of inertia of a body aren't set, then it is considered a uniform disk),

α and β – angles of the planes inclination,

f and δ – friction coefficients of sliding and rolling (respectively).

Masses is set in kilograms, the linear sizes – in meters, angles – in radians.

The mass of bodies are accepted on formulas

$m_1=K_{m1}\cdot m, \quad m_2=K_{m2}\cdot m, \quad m_3=K_{m3}\cdot m, \quad m_4=K_{m4}\cdot m.$

Radiuses of wheels $R_2=0.30$ m, $R_3=0.20$ m (if there is no instruction on the scheme),

Radiuses of gyration $i_2=0.20$ m, $i_3=0.15$ m.

Friction coefficient of sliding $f=0.2$, rolling friction coefficient $\delta=0.25\cdot10^{-2}$ m.

Angles $\alpha=K_\alpha\cdot\pi/12$ and $\beta=K_\beta\cdot\pi/12$.

To accept spring constant on a formula $c=K_c\cdot m_1 g/L$, where $g=9.81$ m/s^2, $L=1.0$ m.

Initial velocity $V_0=K_V\cdot 1$ (m/sec).

All numerical coefficients (*K_{m1},…, K_V*) and dependence of *$F^a(S)$* are specified by the teacher at delivery of a task, for example, as it is specified in the table 1.

Table 1 - Table of basic data

№ one by one	2	3	4
K_{m1}	1.0	1.0	1.0
K_{m2}	2.0	3.0	1.0
K_{m3}	2.0	1.0	2.0
K_{m4}	1.0	1.0	1.0
K_{α}	3.0	2.0	4.0
K_{β}	3.0	4.0	2.0
K_c	2.0	3.0	1.0
K_V	1.0	2.0	1.0
$F^a(S)$	$Mg\cdot Sin(\pi S/2S_2)$	$Mg\cdot S/S_2$	$Mg\cdot(S/S_2)^2$
M	$3.0\cdot m$	$3.0\cdot m$	$3.0\cdot m$
S_2	0.5	0.5	0.5

Schemes of mechanisms are shown in position of static balance (figure 1).

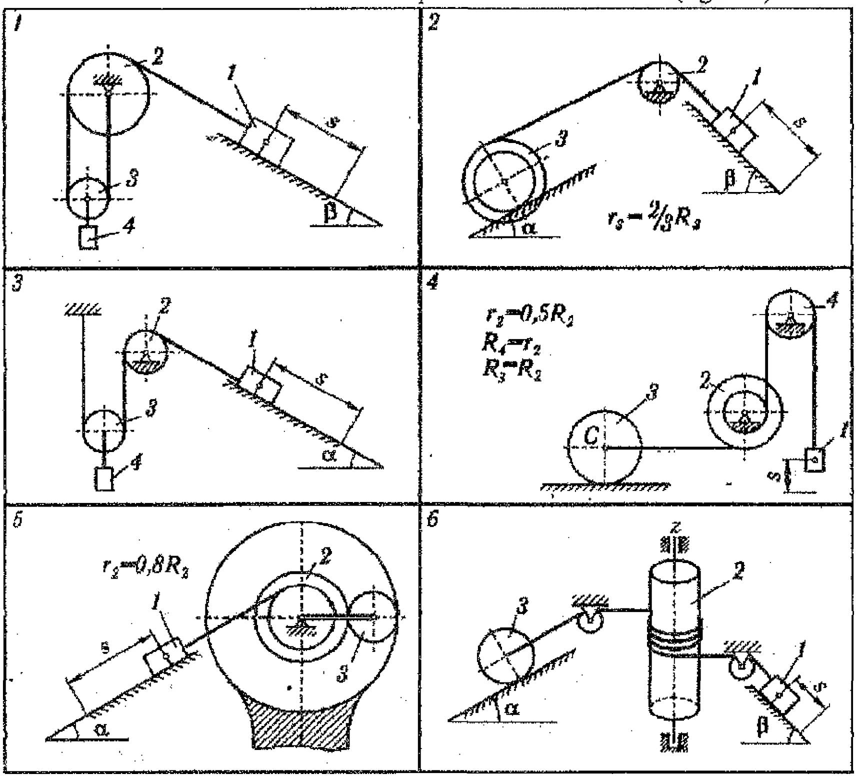
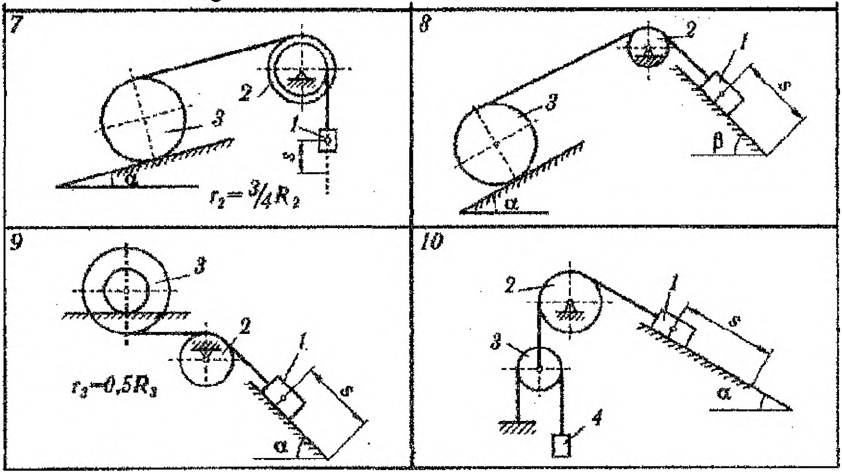


Figure 1 – Schemes of tasks by options

Continuation of the figure 1



Work is performed in the sequence:

- to show the scheme of the mechanism, supplemented by a spring;
- show all existing in the system of external forces and moments;
- to make calculated schemes and to define static deformation of a spring ***;
- to show system in any provision (at $S_1<S<S_2$);
- to find kinetic energy of system and to define its initial value;
- to find work done of the applied forces;
- to find dependence of $V(S)$ and to define $V(S_2)$;
- to find acceleration of the first body and effort in thread between the first and second body (using the main equation of dynamics of a point or Dalamber's principle for a point), to carry out calculations for $S=S_2$.

*** the static deformation of a spring is allowed to define by the principle of possible displacement (Lagrange's principle).

Example:

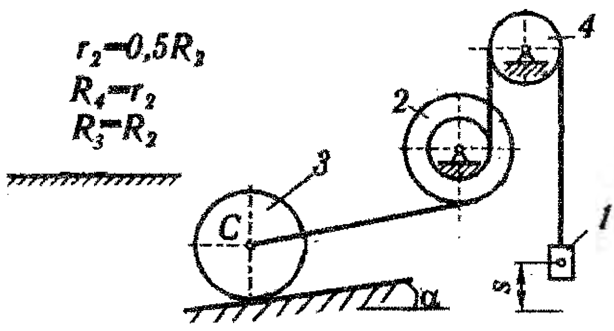


Figure 2

Basic data: $K_{m1} = 3, K_{m2} = 1, K_{m3} = 1, K_{m4} = 2, K_\alpha = 4, K_c = 1, K_V = 1,$

$M = 3 \cdot m,\ S_2 = 0{,}5.\ Fa(S) = M \cdot g \cdot e^{(\frac{S}{S_2})} = 3 \cdot m \cdot g \cdot e^{(\frac{S}{0.5})} = 3 \cdot g \cdot m \cdot e^{2{,}0 \cdot S}.$

The mass of bodies are accepted on formulas:

$m_1 = K_{m1} \cdot m = 3m$ [kg], $m_2 = K_{m2} \cdot m = m$ [kg],

$m_3 = K_{m3} \cdot m = m$ [kg], $m_4 = K_{m4} \cdot m = 2m$ [kg].

Radiuses of wheels $R_2 = 0{,}3$ m, ($R_3 = R_2 = 0{,}3\ m$).

Inertia gyration $i_2 = 0{,}2\ m$

Rolling friction coefficient $\delta = 0{,}5 \cdot 10^{-2} m$.

Angle $\alpha = K_\alpha \cdot \frac{\pi}{12} = 4\frac{\pi}{12} = \frac{\pi}{3}$.

To accept rigidity of spring (constant) on a formula:

$c = K_c \cdot m_1 \cdot \frac{g}{L} = 3 \cdot m \cdot \frac{g}{1} = 3mg.$

Initial velocity $V_0 = K_v \cdot 1 = 1\left(\frac{m}{sec}\right)$.

Decision:

We will represent the scheme of the mechanism added with a spring, and we will show all external forth factors existing in system.

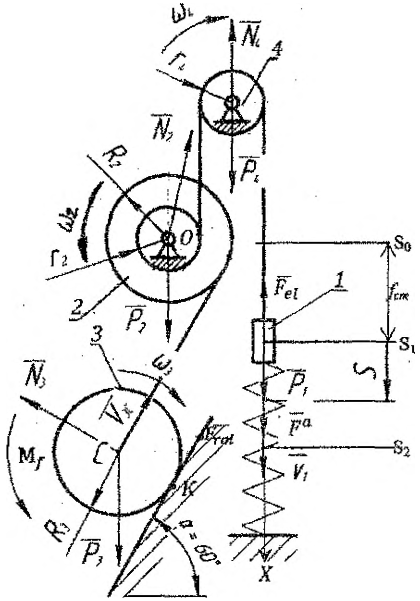


Figure 3

Where: $\boldsymbol{F_{rol}}$ – rolling friction; M_f – the moment from rolling friction; $\boldsymbol{F_{el}}$ – elastic force; S_0 – position of a body 1 at not deformed spring, i.e. a body 1 is kept by some external force.

1. We will consider the displacement of the mechanical system consisting of bodies 1-4. For definition of $\boldsymbol{V_1}$ we will use the theorem in the change of kinetic energy:

2. We define kinetic energy T.

$$T = T_1 + T_2 + T_3 + T_4. \qquad (12)$$

3. Considering that the body 1 moves translatory, bodies 2 and 4 rotate around fixed axles, the body 3 moves plane-parallel, we will receive:

$$T_1 = \frac{m_1 \cdot V_1^2}{2},\ T_2 = \frac{I_2 \cdot \omega_2^2}{2},\ T_3 = \frac{m_3 \cdot V_{3C}^2}{2} + \frac{I_3 \cdot \omega_3^2}{2},\ T_4 = \frac{I_4 \cdot \omega_4^2}{2} \qquad (13)$$

where I_2 – moment of inertia of bodies (on a condition it is accepted $i_2=0,2\ m$, $r_2=0,5R_2=0,5 \cdot 0,3=0,15\ m$, $R_4=r_2=0,15\ m$, $R_2=R_3=0,3\ m$).

We express all velocities entering here through required size V_1:

$$\omega_2 = \frac{V_1}{r_2} = \frac{V_1}{R_4} = \frac{V_1}{0,15},$$

$$V_{3C} = \omega_2 \cdot R_2 = \frac{V_1}{0,15} \cdot 0,3 = 2,0 \cdot V_1$$

$$\omega_3 = \frac{V_{3C}}{R_3} = \frac{2 \cdot V_1}{0,3} = 6,67 \cdot V_1. \qquad (14)$$

Then, substituting expression (14) and (13), we will receive:

$$T_1 = \frac{3 \cdot m \cdot V_1^2}{2}.$$

$$T_2 = \frac{0,04 \cdot m \cdot \left(\frac{V_1}{0,15}\right)^2}{2} = 0,89 m V_1^2$$

$$T_3 = \frac{m \cdot (2 \cdot V_1)^2}{2} + \frac{0,045 \cdot m \cdot (6,67 \cdot V_1)^2}{2} = 3 m V_1^2.$$

$$T_4 = \frac{0,0225 \cdot m \cdot \left(\frac{V_1}{0,15}\right)^2}{2} = 0,5 m V_1^2.$$

Then expression (12) will be written as:

$$T = \frac{3 \cdot m \cdot V_1^2}{2} + 0,89\, m V_1^2 + 3 \cdot m V_1^2 + 0,5 \cdot m V_1^2. \qquad (15)$$

This expression defines kinetic energy of system in dependence on the velocity of the 1st body.

4. We define initial value of kinetic energy of system:

$$T_I = T\,(V_I = V_0).$$

$$T_I = 5,89\, m \cdot V_0^2 = 5,89 \cdot m \cdot 1^2 = 5,89 m \text{ [Joules]} \qquad (16)$$

5. Further we will find the sum of work done of all acting external forces on displacement which will have system points when the load ***1*** passes a way of ***S***. We will enter designations for displacement of a load ***1***: $\boldsymbol{S_1 = S}$

$$_4 = \frac{S_1}{R_4} = \frac{S}{0,15},\ _2 = \frac{S_1}{r_2} = \frac{S}{0,15},$$

$$S_{3C} = {}_2 \cdot R_2 = \frac{S}{0,15} \cdot 0,3 = 2S$$

$$_3 = \frac{S_{3C}}{R_3} = \frac{2 \cdot S}{0,3} = 6,67 S \qquad (17)$$

We will find initial and final lengthening of a spring. For this purpose we will consider a condition of balance of a body 1 in the figure 4.

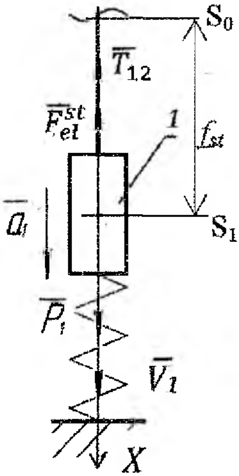


Figure 4

Where: F_{el}^{st} – elastic force at static balance of system; T_{12} – tension force in thread.

We will define a condition of the deformed spring f_{cm}:

$$\overrightarrow{P_1} + \overrightarrow{T_{12}} + \overrightarrow{F_{el}^{st}} = 0$$

$$\sum F_x = 0; \quad P_1 - F_{el}^{st} - T_{12} = 0 \tag{18}$$

$$P_1 = m_1 \cdot g = 3 \cdot m \cdot g$$

$$f_{st} \cdot c = P_1 - T_{12} \tag{18'}$$

$$F_{el}^{st} = f_{st} \cdot c \tag{19}$$

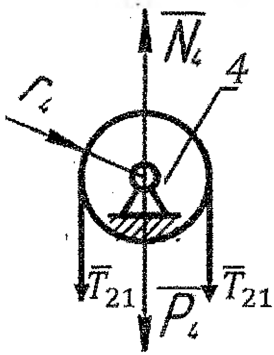


Figure 5

For finding of f_{st} we will find T_{12}. We will consider a body of 4 (fig. 5) in balance. Effort in the threads, thrown through the block 4, identically. $T_{12} = T_{21}$.

We will consider in balance a body 2. (fig. 6)

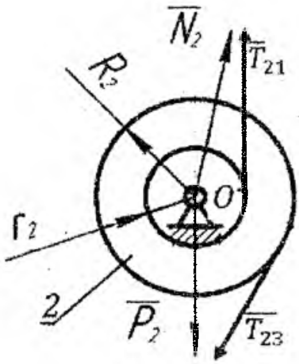


Figure 6

$$\Sigma M_0 = 0;\ T_{21} \cdot r_2 - T_{23} \cdot R_2 = 0 \quad (20)$$

$$T_{21} = T_{23} \cdot R_2 / r_2 \quad (20')$$

We will consider in balance a wheel 3 (figure 7). We will notice that
We will work out the equation of the moments of all forth factors w.r.t. point of **K** (*ICZV - instantaneous center of zero velocity*).

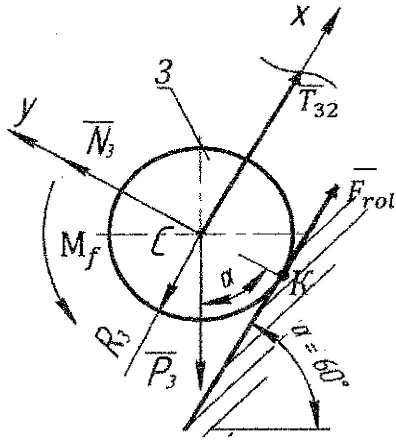


Figure 7

$$\Sigma M_K = 0;\ M_f + P_3 \cdot sin\alpha \cdot R_3 - T_{32} \cdot R_3 = 0 \quad (21)$$

$$T_{32} = M_f + P_3 \cdot sin\alpha \cdot R_3 / R_3 \quad (21')$$

$$M_f = N_3 \cdot \delta \quad (22)$$

$$\Sigma F_y = 0;\ -P_3 \cdot cos\alpha + N_3 = 0 \quad (23)$$

$$N_3 = P_3 \cdot cos\alpha;\quad P_3 = m_3 g;\qquad N_3 = m_3 \cdot g \cdot cos\alpha \quad (23')$$

We substitute (23'), (22), (21'), (20') in (18') and expressing, we will receive:

$$f_{st} = \frac{3\cdot m\cdot g - \frac{R_2}{r_2}\frac{m\cdot g\cdot cos\alpha\cdot\delta + m\cdot g\cdot sin\alpha\cdot R3}{R3}}{c} \quad (24)$$

$$f_{st} = \frac{3\cdot m\cdot g - 2\frac{m\cdot g\cdot 0{,}5\cdot 0{,}005 + m\cdot g\cdot 0{,}867\cdot 0{,}3}{0{,}3}}{3\cdot m\cdot g} = 1 - 0{,}58 = 0{,}42\ m.$$

$f_{\text{к}} = f_{st} + s_1 = 0{,}42 + S$ since the load 1 moves towards further compression of a spring.

The work of the elastic force of the spring:

$$A(F_{el}) = -\frac{c}{2}\cdot((f_{st}+S)^2 - f_{st}^2) = -\frac{3mg}{2}(S^2 + 2\cdot S\cdot f_{st}) \quad (25)$$

Work done of active force F^a:

$$A(F^a) = \int_0^S F^a(S)dS = \int_0^S 3\cdot m\cdot g\cdot e^{2\cdot S}dS = \int_0^S 3mge^{2S}dS = 3mg\int_0^S e^{2S}dS =$$

$$3mg\cdot(\frac{e^{2S}}{2} - \frac{e^0}{2}) = 1{,}5m\,g\,(e^{2\cdot S} - 1) \quad (26)$$

We will find works done of all other active forces:

$$P_1 = m_1\cdot g = 3mg$$

$$A(P_1) = P_1\cdot s_1 = 3mgS \quad (27)$$

We will consider a wheel 3 fig. 4):

$$P_3 = m_3\cdot g = mg$$

$$A(P_3) = -P_3\cdot \sin(\alpha)\cdot S_{3C} = -2\cdot S\cdot m\cdot g\cdot \sin(\alpha) \quad (28)$$

$$A(M_f) = -0{,}005\cdot m\cdot g\cdot\cos(\alpha)\cdot 6{,}67\cdot S = -0{,}033\cdot S\cdot m\cdot g\cdot\cos(\alpha) \quad (29)$$

Work done of forces of $\vec{N}_2$, $\vec{P}_2$, $\vec{N}_4$, $\vec{P}_4$ equal to zero since their points of application fixed. Force $\vec{N}_3$ is perpendicular to displacement of a wheel therefore its work done is also equal to zero.

The right member of equation (11) taking into account expressions (25)-(29) will be written down:

$$\sum A_{\text{к}} = A(F^a) + A(P_1) + A(P_3) + A(M_f) + A(F_{el}) \quad (30)$$

$$\sum A_{\text{к}} = m\cdot g\cdot(1{,}5\cdot e^{2\cdot S} - 1{,}5) + 3\cdot m\cdot g\cdot S - 2\cdot S\cdot m\cdot g\cdot\sin(\frac{\pi}{3})$$

$$-0{,}0333\cdot S\cdot m\cdot g\cdot(\frac{\pi}{3}) - \frac{3\cdot m\cdot g}{2}\cdot(S^2 + 2\cdot S\cdot f_{st})$$

$$\sum A_{\text{к}} = mg(-0{,}0087\cdot S + 1{,}5\cdot e^{2\cdot S} - 1{,}5\cdot S^2\cdot 1{,}5) \quad (30')$$

6. Determination of velocity. Substituting expression (30'), (15) and (16) in the equation (11), we will come to equality:

$$5{,}89\cdot V_1^2\cdot m - 5{,}89\cdot m = (-0{,}0087\cdot S + 1{,}5e^{2\cdot S} - 1{,}5\cdot S^2 - 1{,}5)mg.$$

$$5{,}89\cdot V_1^2 - 5{,}89 = -0{,}085\cdot S + 14{,}715\cdot e^{2\cdot S} - 14{,}715\cdot S^2 - 14{,}715$$

From where:

$$V_1 = \sqrt{\frac{S + 14{,}715\cdot e^{2\cdot s} - 14{,}715\cdot S^2 - 14{,}715 + 5{,}889}{5{,}889}} =$$

$$= \sqrt{0{,}014\cdot S + 2{,}499\cdot e^{2\cdot S} - 2{,}499\cdot S^2 - 1{,}5} \quad (31)$$

This expression defines the law of change of velocity of the 1st body depending on its displacement.

7. We determine the dependence of the yarn tension between the bodies 1 and 2. For this purpose it is necessary to know acceleration of a body 1.

$$a=\frac{d}{dt}V$$

We will pass to a variable S:

$$a=\frac{d}{dt}V=\frac{d}{dt}V\cdot\frac{dS}{dS}=\left(\frac{d}{dS}V\right)\cdot\left(\frac{d}{dt}S\right)=V\left(\frac{d}{dS}V\right)=\frac{dV^2}{2dS} \quad (32)$$

Then acceleration of the 1st body taking into account (31):

$$a_1=\frac{d}{dS}\left[\frac{1}{2}(-0{,}014\cdot S+2{,}499\cdot e^{2\cdot S}-2{,}499\cdot S^2-1{,}5)\right]=$$
$$=a_1=2{,}499\cdot e^{2S}-2{,}499\cdot S-0{,}007 \quad (33)$$

8. For definition of a tension in thread, we will mentally cut thread and it is action it on a body 1 replace throw reaction of T_{dyn} (fig. 8).

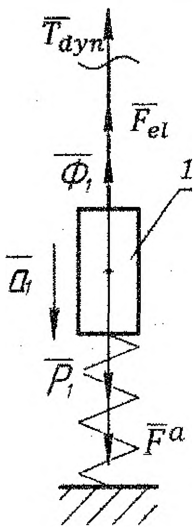


Figure 8

Where: T_{dyn} – effort in thread at the motion of solid 1.

Then on the basis of Dalamber's principle it is had:

$$P_1+F^a-\Phi_1-F_{el}-T_{dyn}=0, \quad (34)$$

where:

$F_{el}=c(f_{st}+S)=3m\cdot g\cdot(0{,}42+S)=3\cdot S\cdot m\cdot g+1{,}26mg$ – elastic force.

$\Phi_1=m_1\cdot a_1=3\cdot m(2{,}499\cdot e^{2S}-2{,}499\cdot S-0{,}007)$ – force of inertia of the first body.

$F^a=F^a(S)=3\cdot m\cdot g\cdot e^{2S}$ – active force.

Expressing from (34) T_{dyn} we will receive:

$$T_{dyn}=P_1+F_a-\Phi_1-F_{el}=3mg+3mge^{2S}-3m(2{,}499e^{2S}-2{,}499\cdot S+$$
$$+0{,}007)-3Smg-1{,}26mg$$

$$T_{dyn} = m(7{,}496\,S + 3\cdot 9{,}81 - 7{,}496e^{2S} + 3\cdot 9{,}81\cdot e^{2S} - 3\cdot S\cdot 9{,}81 - 0{,}021 - - 1{,}26\cdot 9{,}81)$$

$$T_{dyn} = m(-21{,}934\cdot S + 21{,}934e^{2S} + 17{,}061). \qquad (35)$$

This expression defines the law of change of effort in thread between the 1st and 2nd body depending on displacement of the 1st body.

9. We will carry out calculations for $S=S_2$:

9.1 Velocity of the 1st body at $S_2 = 0{,}5\ [m]$ from a formula (31):

$$V_1 = \sqrt{-0{,}014 \cdot S_\kappa + 2{,}499 \cdot e^{2S_\kappa} - 2{,}499 \cdot S_\kappa^2 - 1{,}5}$$

$$V_1 = \sqrt{-0{,}014 \cdot 0{,}5 + 2{,}499 \cdot e^{2\cdot 0{,}5} - 1{,}5} = 2{,}16\ [m/s].$$

9.2. Thread tension between the 1st and 2nd body at $S_2 = 0{,}5\ [m]$ from a formula (35).

$$T_{dyn} = m(21{,}934 \cdot e^{2S} - 21{,}934 \cdot S_k + 17{,}061)$$

$$T_{dyn} = \mathrm{m}(21{,}934 \cdot \mathrm{e}^{2\cdot 0{,}5} - 21{,}934 \cdot 0{,}5 + 17{,}061) = 65{,}65m\ [H]$$

9.3. Acceleration of the 1st body at $S_2 = 0{,}5\ [m]$ from a formula (33).

$$a_1 = 2{,}499 \cdot e^{2S_\kappa} - 2{,}499 \cdot S_\kappa - 0{,}007$$

$$a_1 = 2{,}499 \cdot e^{2\cdot 0{,}5} - 2{,}499 \cdot 0{,}5 - 0{,}007 = 5{,}53\ [\frac{m}{s^2}]$$

Answer: $V_1(S) = \sqrt{-0{,}014 \cdot S + 2{,}499 \cdot e^{2S} - 2{,}499 \cdot S^2 - 1{,}5}$,

$T_{dyn}(S) = m\,(-21{,}934\cdot S + 21{,}934\cdot e^{2S} + 17{,}061)$,

$a_1(S) = -2{,}499\cdot S + 2{,}499 \cdot e^{2S} - 0{,}007$,

$V_1(S_2) = 2{,}16\ [m/s\,]$,

$T(S_2) = 65{,}65m\ [H]$,

$a_1(S_2) = 5{,}53[m/s^2]$.

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