SIMULATION AND MODELLING OF FORCES AND POWERS FOR STATICALLY BALANCED MULTI-ROPE HOISTING MACHINERY USING SOLIDWORKS®

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Abstract. *The present study introduces a method for simulation and modelling of statically balanced multi-rope hoisting machinery to the purpose of studying variation according to the hoisting stage of forces and powers at the periphery of the driving wheel. SolidWorks® software was used in order to achieve such purpose. The components of the technical system (driving wheel, hoisting containers, traction and balancing cables) were built and then assembled into a virtual system Geometrical and mechanical connections were applied upon the created assembly. By means of using the calculation facilities of SolidWorks® software and imposing the acceleration of the actuation engine, variation diagrams were drawn for acceleration, speed and forces at the periphery of the driving wheel, as well as for power according to hoisting stages. The scenarios of actuating hoisting machineries using asynchronous or direct current engines were studied.*

Keywords: *tachogram, acceleration, speed, distance, force, power, gravity.*

1. Introduction

Hoisting machineries have cyclic operation. The size of the actuation power, as well as the absorbed power, depend on the tachogram form, the shape of which being determined by the actuation mode of the hoisting machinery, technological conditions of operation, but also by restrictions imposed by operational safety.

Similar to tachogram tracing, the diagrams for forces and power variations are performed starting from acceleration variation.

The acceleration variation mode is imposed by the mechanical characteristics of the actuation engine. Classic actuation scenarios will be considered: asynchronous engine (acceleration during initiation has a constant value) and direct current engine (acceleration during initiation has a linear variation).

The relation that determines force variation at the periphery of the cable rolling component is[1]:

$$F = [k \cdot Q_u + (q - q_1) \cdot (H - 2 \cdot x)] \cdot g \pm a \cdot \sum m \quad (1)$$

where:

H - transportation distance (m);
x - intermediary distance (m);
Q_u - transported useful mass (kg);
q - specific mass of the traction cable (kg/m);
q_1 - specific mass of the balancing cable (lg/m);
a - acceleration (m/s^2);
$\sum m$ - sum of moving masses, reduced to the periphery of the rolling cable component (kg);
k - coefficient used for assessment of friction forces (0,15...0,2);
g - gravitational acceleration.

2. Variation of forces and powers for statically balanced hoisting machineries actuated by asynchronous engine

Given the fact that for statically balanced hoisting machinery q_1=q, relation (1) – defining variation at the periphery of the rolling element – will now be:

$$F = k \cdot Q_u \cdot g \pm a \cdot \sum m \quad (2)$$

Actuation power is determined using the following relation:

$$P = F \cdot v \quad (3)$$

where:

v - transportation speed (m\s).

The measures on which the diagrams tracing are based are shown in Table 1. Six distinct points are presented, corresponding to a trapezoidal tachogram. Values are indicated for every point, as well as calculation relations corresponding to the following measures: acceleration, speed, space, force and power[2].

In Figure 1 it is shown which graph drawings correspond to variation of acceleration, speed, force and actuation power in this scenario[3].

It is noticeable that in the scenario where the hoisting machinery is statically balanced – relation (2) – the force variation on the periphery of the rolling element no longer depends on the distance covered up to a given moment, being constant for every period of the three transportation stages.

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[1] [1], [2], [4]
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Table 1 – Variation of forces and powers according to hoisting stages for statically balanced hoisting machineries actuated by asynchronous engine

	Hoisting stage	a (m/s^2)	v (m/s)	x (m)	F (N)	P (W)
1	Beginning of acceleration stage	a_1	0	0	$F_1 = kQ_u g + a_1 \sum m$	$P_1 = F_1 v = 0$
2	End of acceleration stage	a_1	v_{max}	h_1	$F_2 = kQ_u g + a_1 \sum m$	$P_2 = F_2 v_{max}$
3	Beginning of uniform running stage	0	v_{max}	h_1	$F_3 = kQ_u g$	$P_3 = F_3 v_{max}$
4	End of uniform running stage	0	v_{max}	h_1+h_2	$F_4 = kQ_u g$	$P_4 = F_4 v_{max}$
5	Beginning of braking stage	$-a_3$	v_{max}	h_1+h_2	$F_5 = kQ_u g - a_3 \sum m$	$P_5 = F_5 v_{max}$
6	End of braking stage	$-a_3$	0	H	$F_6 = kQ_u g - a_3 \sum m$	$P_6 = F_6 v = 0$

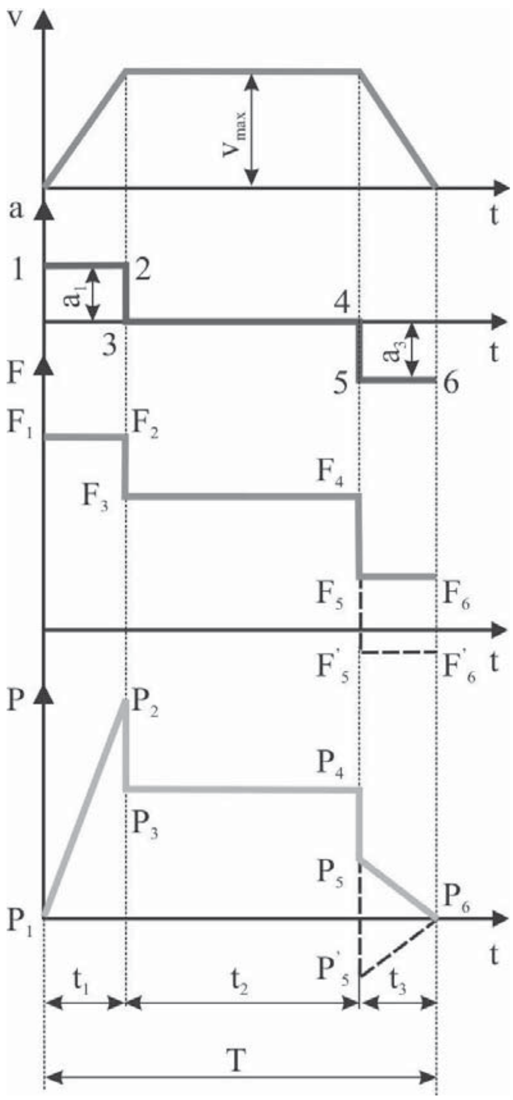

Figure 1 Variation of forces and powers for asynchronous engine actuation

3. Variation of forces and powers according to hoisting stages for statically balanced hoisting machineries actuated by direct current engine

Similar to the statically balanced hoisting machineries actuated by asynchronous engine, in the direct current engine actuation scenario the relations for calculating forces and powers are shown in chapter 2, relations (2) and (3).

Table 2 points out the measures that diagrams tracing is based upon. In this scenario, five distinct points were considered in correspondence with a tachogram. Values are indicated for every point, as well as calculation relations corresponding to the following measures: acceleration, speed, distance, force and power.

Figure 2 presents the graph drawings corresponding to variation of acceleration, speed, force and actuation power for statically balanced hoisting machineries actuated by direct current engine[4].

In the direct current engine actuation scenario, the force is constant only for tachogram stages where the acceleration is constant: uniform running stage and braking stage.

In relation (2), it is shown that, in this scenario, the only time-variable measure is the acceleration. This has decreasing linear variation, which determines parabolic variation of force at the periphery of the cable rolling component. Given the decreasing acceleration, the shape of the force will be a convex parabolic. The acceleration derivative determines the convex or concave nature of the force graph drawing.

[1][1], [2], [4], [5]

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Table 2 - Variation of forces and powers according to hoisting stages for statically balanced hoisting machineries actuated by direct current engine

	Hoisting stage	a (m/s^2)	v (m/s)	x (m)	F (N)	P (W)
1	Beginning of acceleration stage	a_1	0	0	$F_1 = kQ_u g + a_1 \sum m$	$P_1 = F_1 v = 0$
2	End of acceleration stage	0	v_{max}	h_1	$F_2 = kQ_u g$	$P_2 = F_2 v_{max}$
3	End of uniform running stage	0	v_{max}	h_1+h_2	$F_3 = kQ_u g$	$P_3 = F_3 v_{max}$
4	Beginning of braking stage	$-a_3$	v_{max}	h_1+h_2	$F_4 = kQ_u g - a_3 \sum m$	$P_4 = F_4 v_{max}$
5	End of braking stage	$-a_3$	0	H	$F_5 = kQ_u g - a_3 \sum m$	$P_5 = F_5 v = 0$

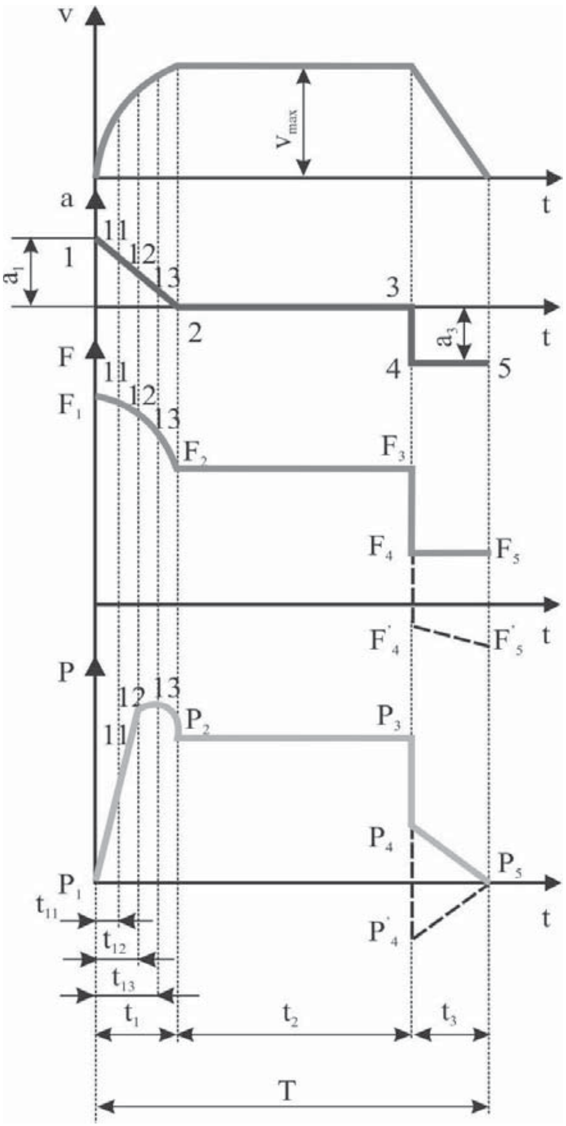

Figure 2 Variation of forces and powers for direct current engine actuation

4. Tracing diagrams of variation of forces and powers using Solid Works®

In order to study the time-related variation of forces at the periphery of the driving wheel and power for statically balanced multi-rope hoisting machinery, I have created a SolidWorks® model of such installation, materialized into an assembly (Figure 3)[5].

A mass – corresponding to the transported useful load – was assigned to the ascending container.

An actuation engine was assigned to the drive component (Kope wheel), as shown in Figure 4, therefore the acceleration variation of the actuation engine can be expressed through points or mathematical expressions.

Simultaneously, the assembly is subject to Earth gravity, as shown in Figure 4. This will act upon those assembly components which are not fastened to the rotation axle of the drive wheel.

The movement of the two transportation containers of the assembly shown in Figure 3 is ensured by means of a gear rack-type joint, established between the hoist machinery driving wheel and the transportation containers. Thus, I have modelled the physical link between cables, hoisting containers and driving wheel by means of a logical link (gear rack-type joint) which can be made available to SolidWorks® users.

Moreover, SolidWorks® allows for assigning gravitational acceleration to the assembly, which will introduce useful mass into the numerical calculation method (Figure 4).

In the absence of gravitational acceleration, both terms of the expression of force at the periphery of the driving wheel would be altered from the numerical calculation point of view.

[5] [3]

For every tachogram to be further presented, the acceleration values were imposed either through points or through mathematical expressions.

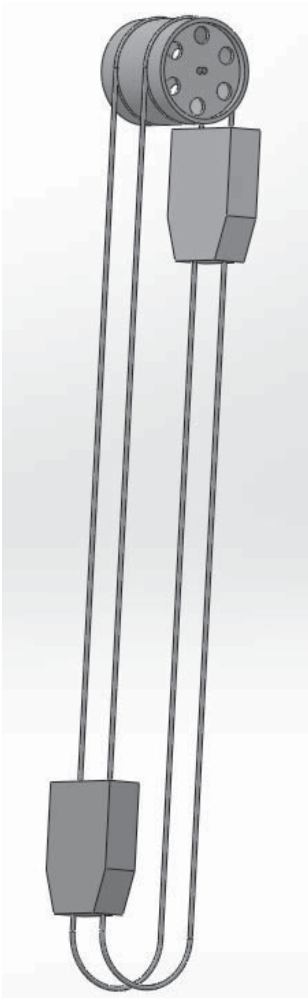

Figure 3 Assembly of statically balanced multi-rope hoisting machinery. The fully loaded transportation container is on the ascending arm

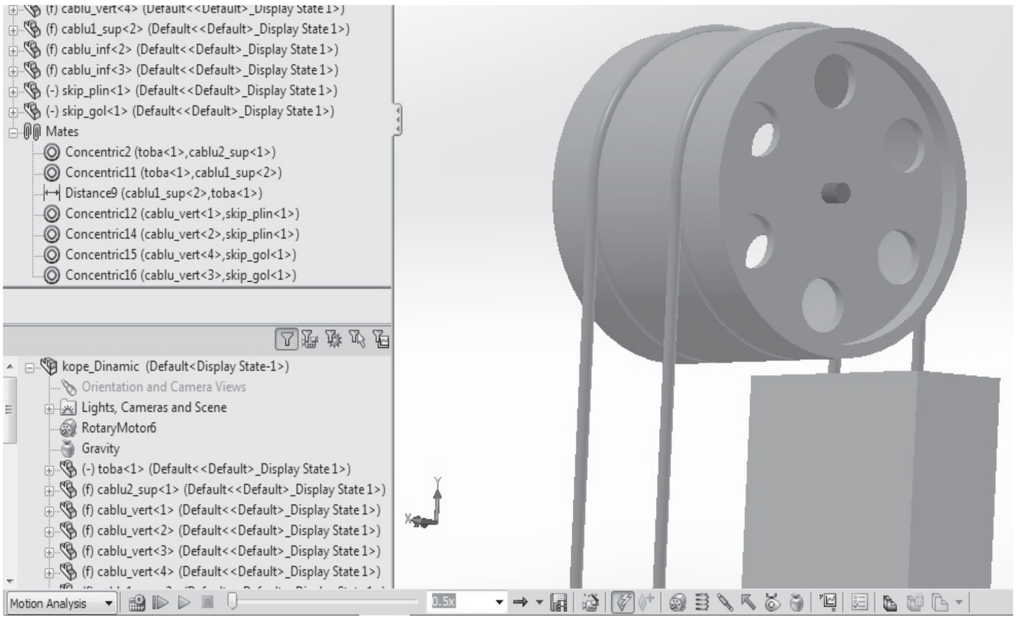

Figure 4 Assigning actuation engine and gravity

4.1. Calculation of forces and powers for hoisting machinery actuated by asynchronous engine

In the scenario of actuation by asynchronous engine of the above-described assembly, in Figure 5 I have presented the method of imposing the acceleration variation of the actuation engine. A seen in Figure 5, compared to the analytical method, acceleration no longer has step-type strict variation. Imposing acceleration variation as a step function – as with analytical methods – leads to impossibility of numerical determination of tachograms and, implicitly, of variation of forces variation at the periphery of the driving wheel and power. For this reason, the acceleration variation in the presented instances does not have the shape of a Heaviside-type function.

Starting from acceleration variation, I have traced the variation diagrams of speed, forces and actuation power according to hoisting stages.

SolidWorks® software allows for tracing of these measurements. Figure 6 shows the tracing method for speed variation. Figure 7 presents the tracing method for force, while tracing method for power is shown in Figure 8. The variation of these measurements is reported to the hoisting stages specific to and installation actuated by an asynchronous engine actuation. The diagrams achieved from simulation are presented in Figure 9.

These diagrams are of non-quantitative nature, since they are not for a specific hoisting installation.

Their purpose is to bring out the generic character of the used simulation and modelling method, the comparison being performed in opposition to analytical methods in specialist literature [1], [2], [4], [5].

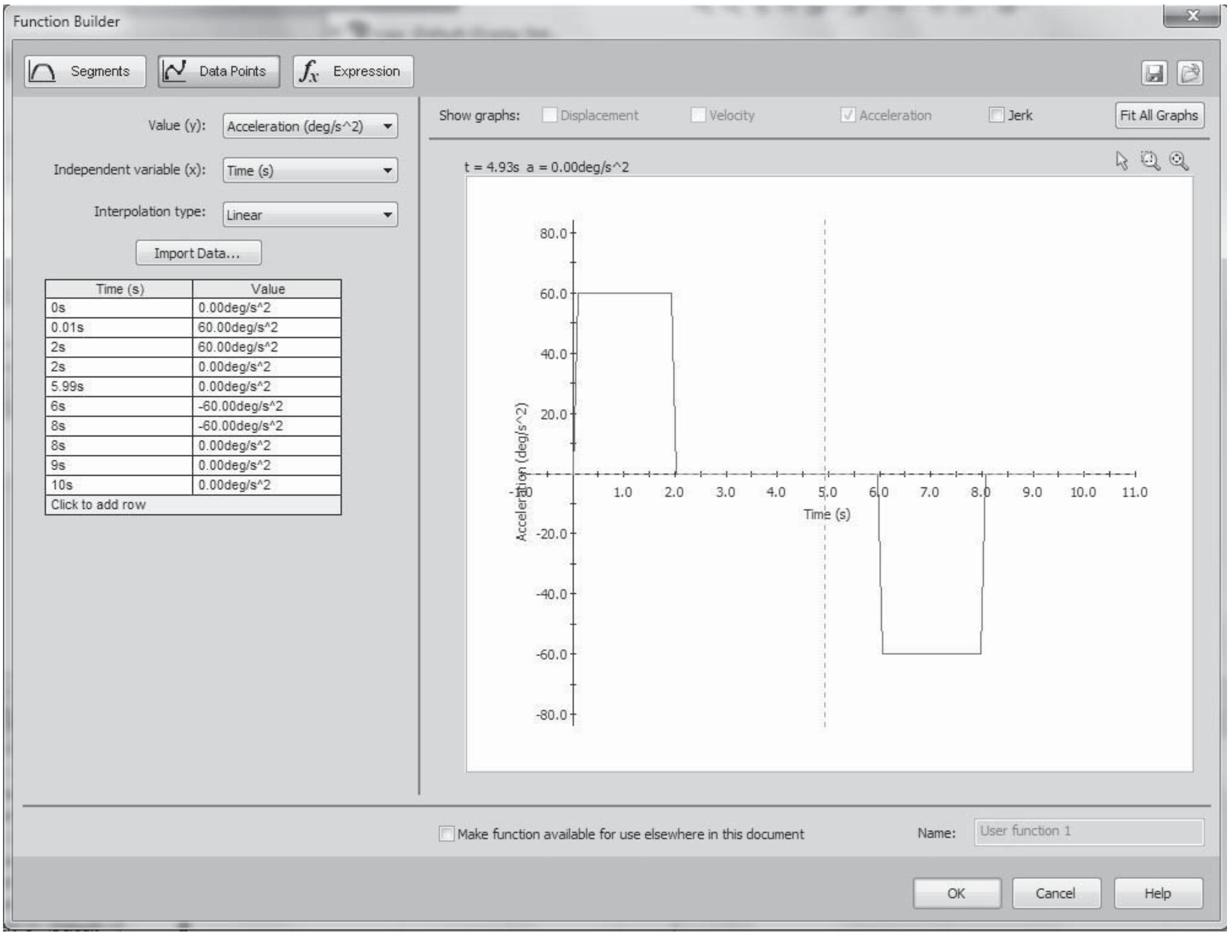

Figure 5 Imposing acceleration variation by points for actuation by asynchronous engine

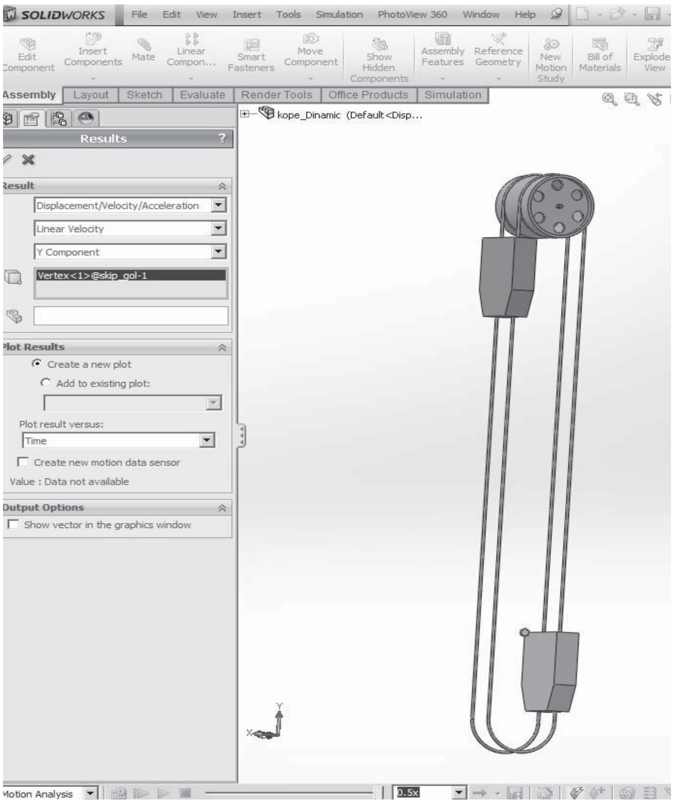

Figure 6 Calculation and speed tracing method

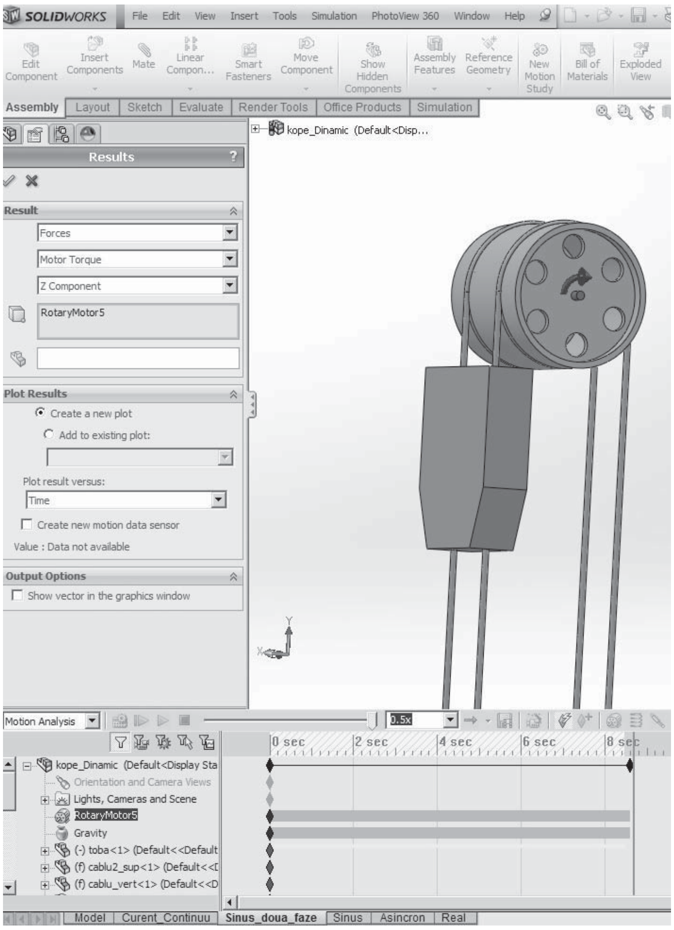

Figure 7 Calculation and forces tracing method

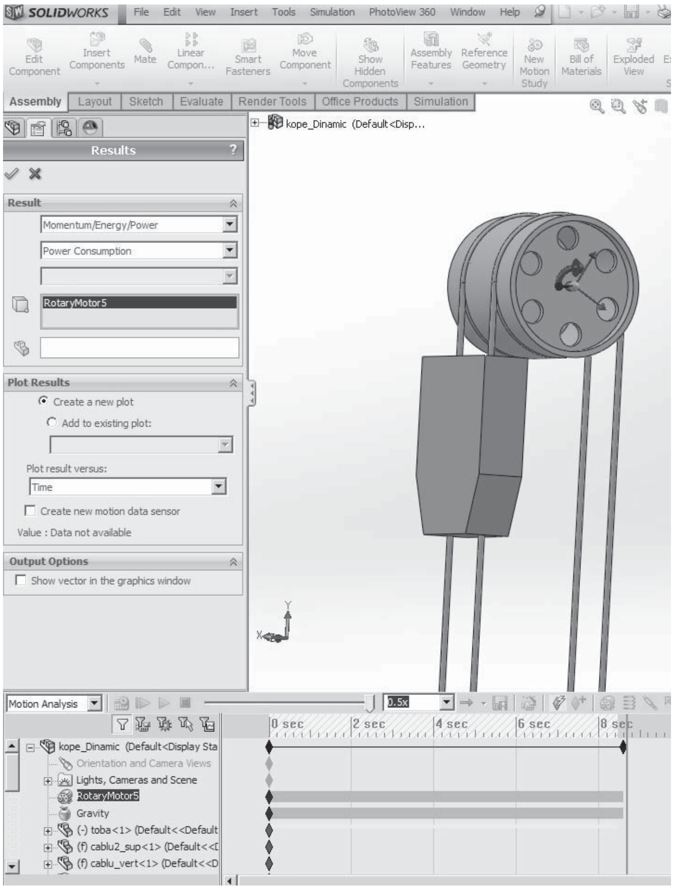

Figure 8 Calculation and power tracing method

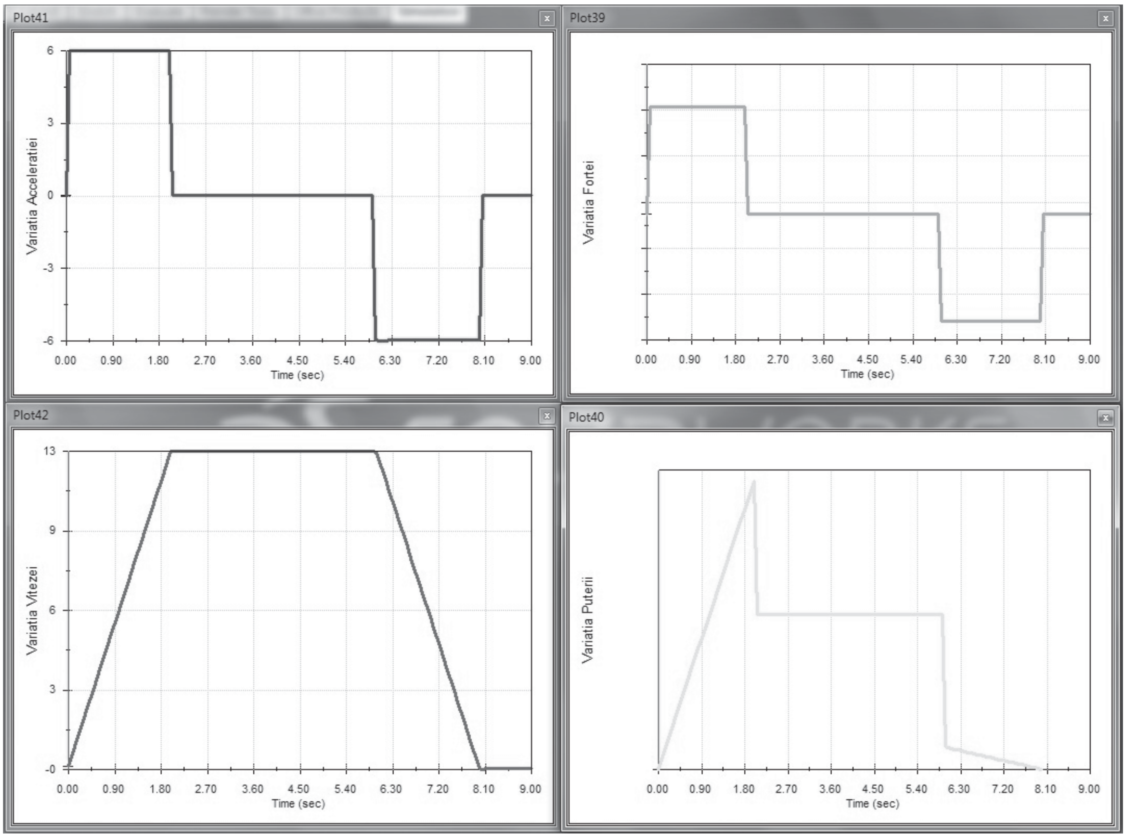

Figure 9 Acceleration, speed, forces and power variation for actuation by asynchronous engine

4.2. Calculation of forces and powers for hoisting machinery actuated by direct current engine

Approaching this actuation method for a hoisting installation is similar to the presentation in paragraph 4.1. This time, I have imposed a variation of speed similar to the representation in Figure 10. The acceleration variation is in linear acceleration with negative slope stage, which will impose – as it will be shown in simulation – a convex parabolic variation of speed. The diagrams resulting from simulation are presented in Figure 11.

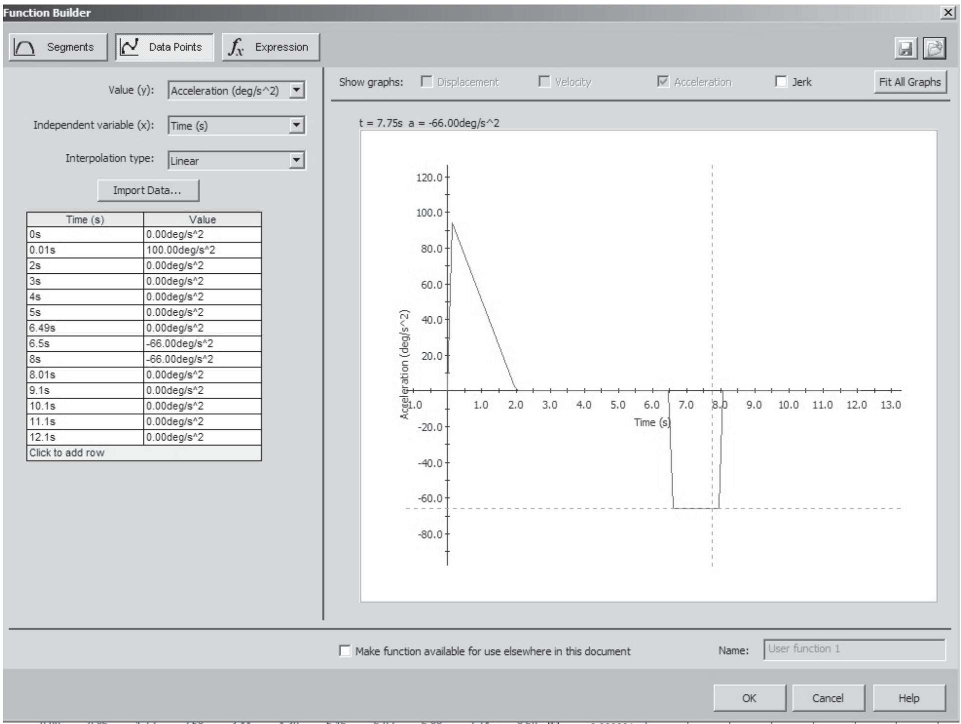

Figure 10 Imposing acceleration variation by point to actuation by direct current engine

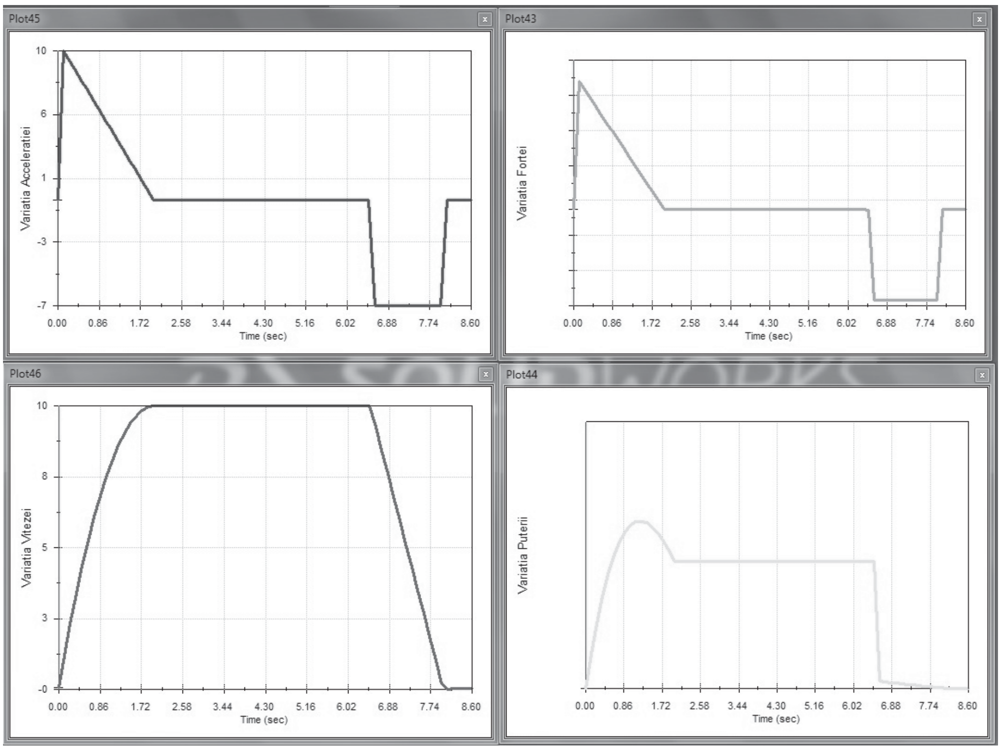

Figure 11 Acceleration, speed, forces and power variation for actuation by direct current engine

To the purpose of limiting shocks through the mechanical system during movement of hoisting containers, elimination of sudden acceleration variations is imposed, resulting in speed variation with smooth transitions from one value to another.

Such solution is the three-stage tachogram, with shock dampening, the simulation of which is shown in Figure 12.

Kinematically speaking, this is a three-stage tachogram with trapezoidal acceleration variation. This actuation type leads to shock dampening.

The shocks value is characterized by the third derivative of distance reported to time:

$$\rho = \frac{d^3x}{dt^3} = \frac{a}{t} \tag{4}$$

The shock size results from the condition of non-existent oscillations in the fully loaded ascending arm of the machinery. For large transportation distances (such as high-depth hoisting machineries) these oscillations will reach substantial values.

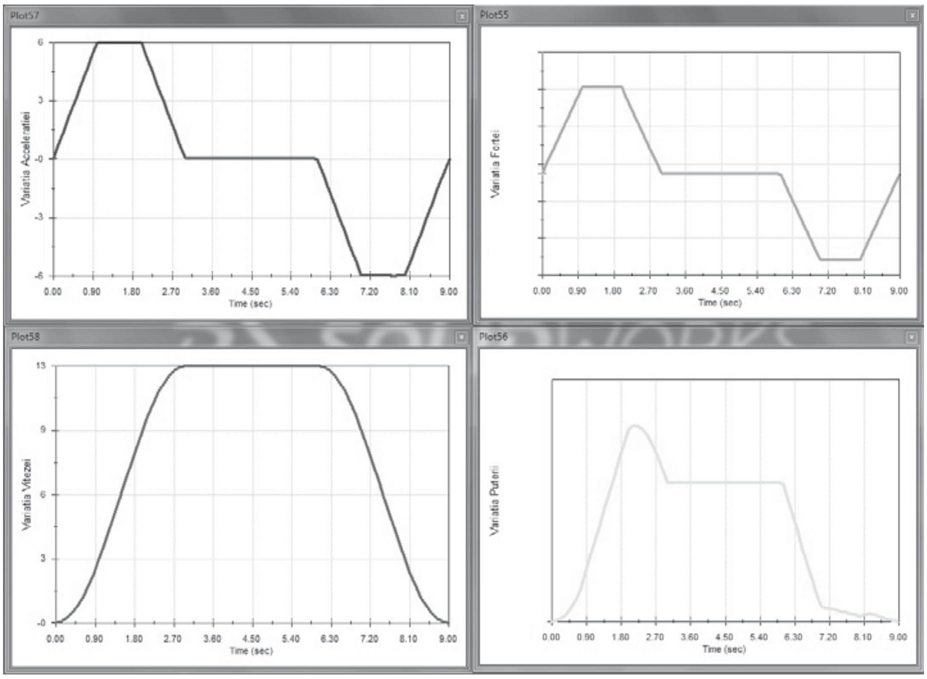

Figure 12 Variation of force and power for three-stage tachogram with trapezoidal acceleration variation

5. Conclusions

Following the analysis of the results achieved from simulation and modelling of a statically balanced multi-rope hoisting installation using SolidWorks® software, the following conclusion can be drawn:

- The achieved graphical results are identical to those in specialist literature, which confirms that the adopted simulation and modelling type is correct.
- The adopted model is useful in case of verifying or designing a hoisting installation. In addition to the information herewith presented, in case of verification or design, the following actions will also be required: up-to-scale components building, selection of components materials, subsequent assembly of a virtual system and application of principles presented in paragraph 4 to the aforementioned virtual system.
- This simulation and modelling type provides the possibility of performing a high number of calculation alternatives in a relatively short time, fast revision of certain outputs by instant change of primary data, as well as possibility of attempting complex forms of actuation engine acceleration variation.
- Approaching the study of hoisting machinery kinematics and dynamics by means of simulation and modelling allows for adopting any form of acceleration variation of the actuation engine, which is almost impossible when using analytical methods.
- The adopted method of study is fundamentally based upon numerical calculations. The results highlighted by the present article are of graphical nature, to allow for comparison with graphical outputs in specialist literature, which are determined through analytical methods ant start from simple acceleration variations (step-type or linear accelerations). Adopting such simplified acceleration variations leads to oversizing the actuation engines.

- The presented method can be applied to the study of kinematics and dynamics of other vertical transportation installations (elevators, for instance).
- From didactic perspective, the simulated and modelled physical system (the hoisting machinery) becomes more accessible and intuitive. A more documented vision is provided regarding the operation mode and principles that stand on the very basis of design and verification of such machinery.

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