STUDY OF FORCE AND POWER VARIATIONS OF STATICALLY BALANCED MULTI-ROPE HOISTING MACHINERY USING SOLIDWORKS®

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Abstract. *Hoisting machineries have an operational duty characterised by cyclic nature and variable load intermittence. In order to determine the actuation power, there is considered a constant load duty that causes the same energetic effect during in the same time interval. Knowing the force values for every tachogram stage allows for determination of actual force and, implicitly, actual power. The actual power value is the measure that imposes the power choice for the actuation engine. Starting from the variation of the accelerations corresponding to a certain actuation mode and using SolidWorks® software program, the present study will present a method for determining forces and power within tachograms range. Moreover, classic scenarios will be presented, corresponding to actuation using asynchronous and direct current engines, by means of both analytical and numerical methods.*

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:

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

where:

H - transportation distance;
x - intermediary distance;
Q_u - transported useful mass;
q - specific mass of the traction cable;
q_1 - specific mass of the balancing cable;
a - acceleration;
$\sum m$ - sum of moving masses, reduced to the periphery of the rolling cable component;
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.

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.

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

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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Table 1 – *Variation of forces and powers for statically balanced hoisting machineries actuated by asynchronous engine*

	Obs.	a	v	x	F	P
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	$F_6 = kQ_u g - a_3 \sum m$	$P_6 = F_6 v = 0$

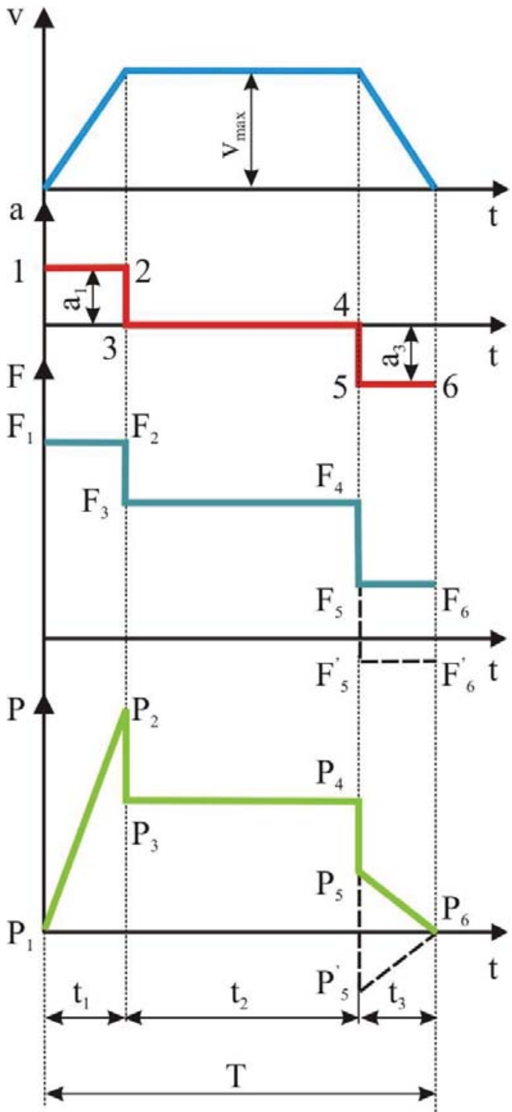

Fig. 1 *Variation of forces and powers for asynchronous engine actuation*

3. Variation of forces and powers 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.

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 stag.

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.

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

	Obs.	a	v	x	F	P
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	$F_5 = kQ_u g - a_3 \sum m$	$P_5 = F_5 v = 0$

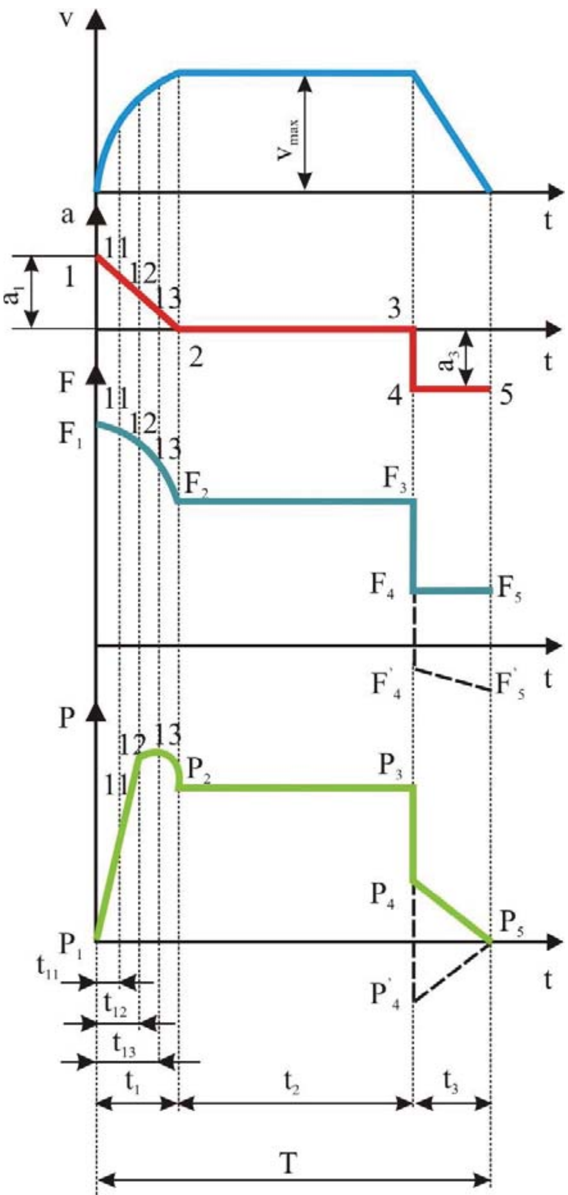

Fig. 2 *Variation of forces and powers for direct current engine actuation*

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).

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.

Assigning gravitational acceleration to the assembly will involve useful mass into the numerical calculation method.

In the absence of gravitational acceleration, both terms of the expression would be altered from the numerical calculation point of view.

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

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

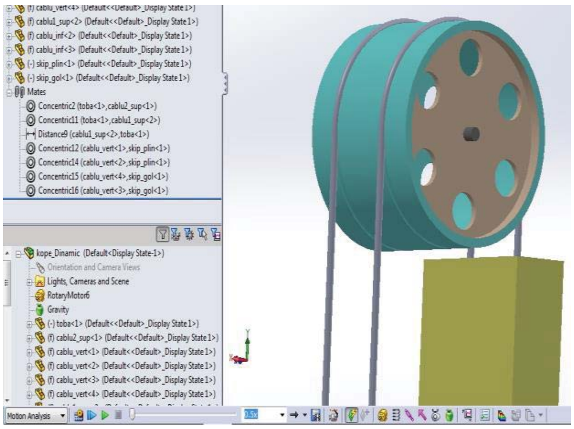

Fig. 4 *Assigning actuation engine and gravity*

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

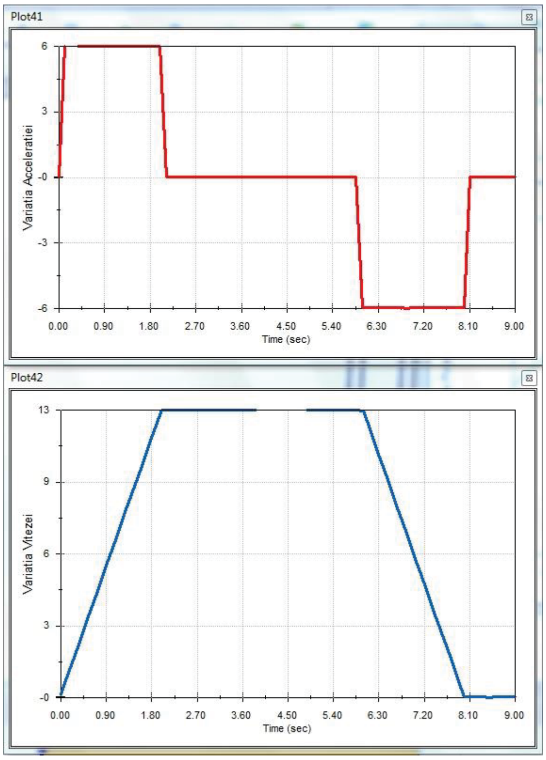

Fig. 5 *Variation of acceleration and speed for asynchronous engine actuation*

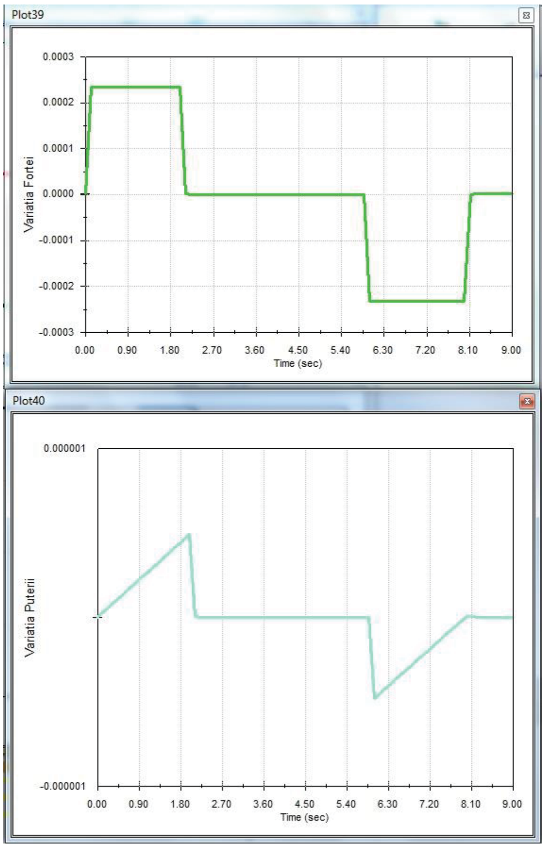

Fig. 6 *Variation of force and power for asynchronous engine actuation*

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

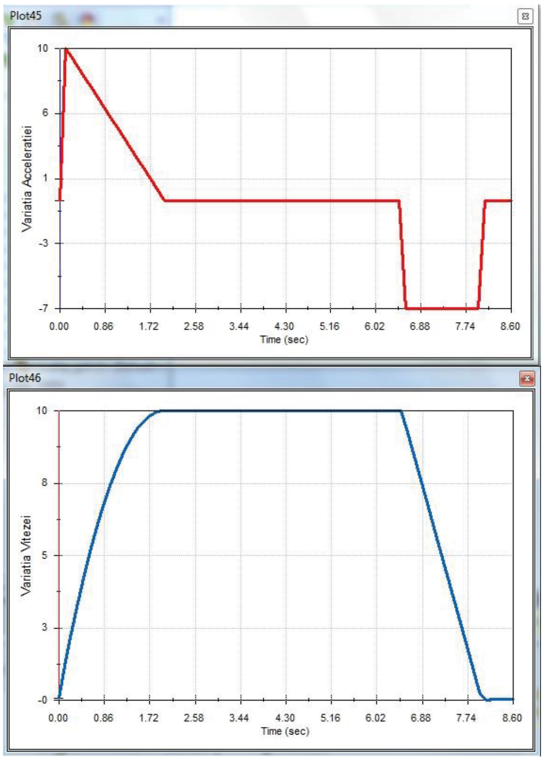

Fig. 7 *Variation of acceleration and speed for direct current engine actuation*

Imposing an acceleration variation formulated as a step function – similarly to analytical methods – leads to impossibility of numerical identification of tachograms and, implicitly, of variation of forces at the periphery of the drive wheel and power. For this reason, variation in the presented instances does not have the Heaviside-type function shape.

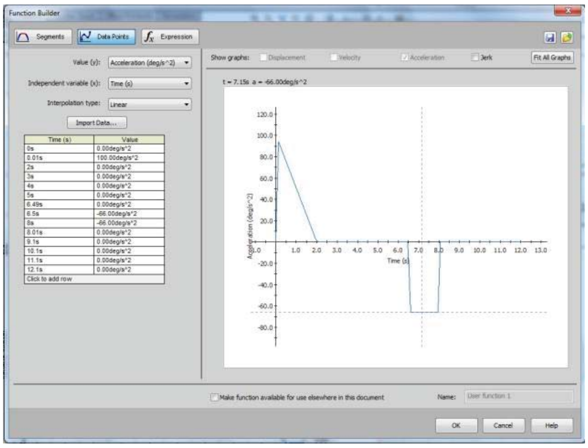

Fig. 8 *Values imposed to acceleration*

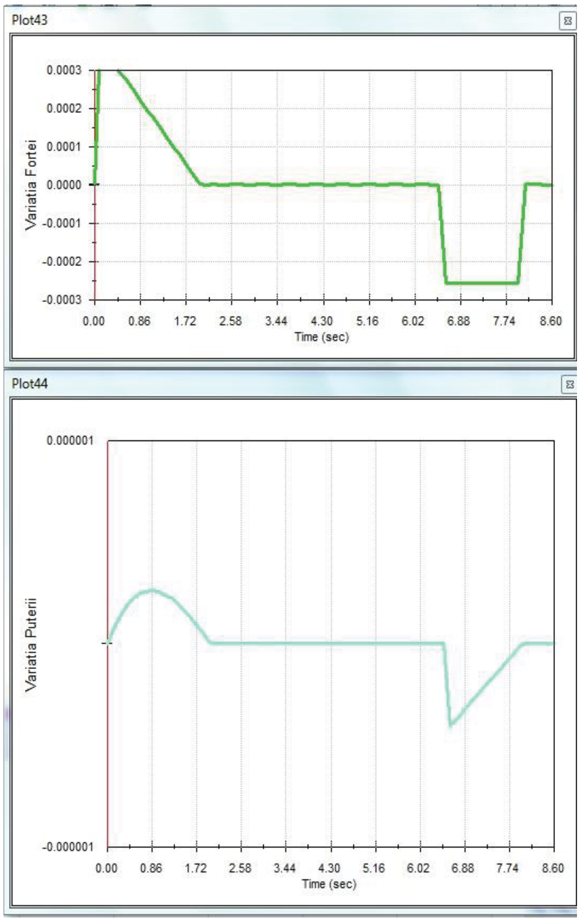

Fig. 9 *Variation of force and power for direct current engine actuation*

For the purpose of limiting shocks through the mechanical system during movement of hoisting containers, there is imposed the elimination of sudden acceleration variations, 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 the screen capture in Figure 10.

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:

$$\rho = \frac{d^3x}{dt^3} = \frac{a}{t} \qquad (4)$$

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.

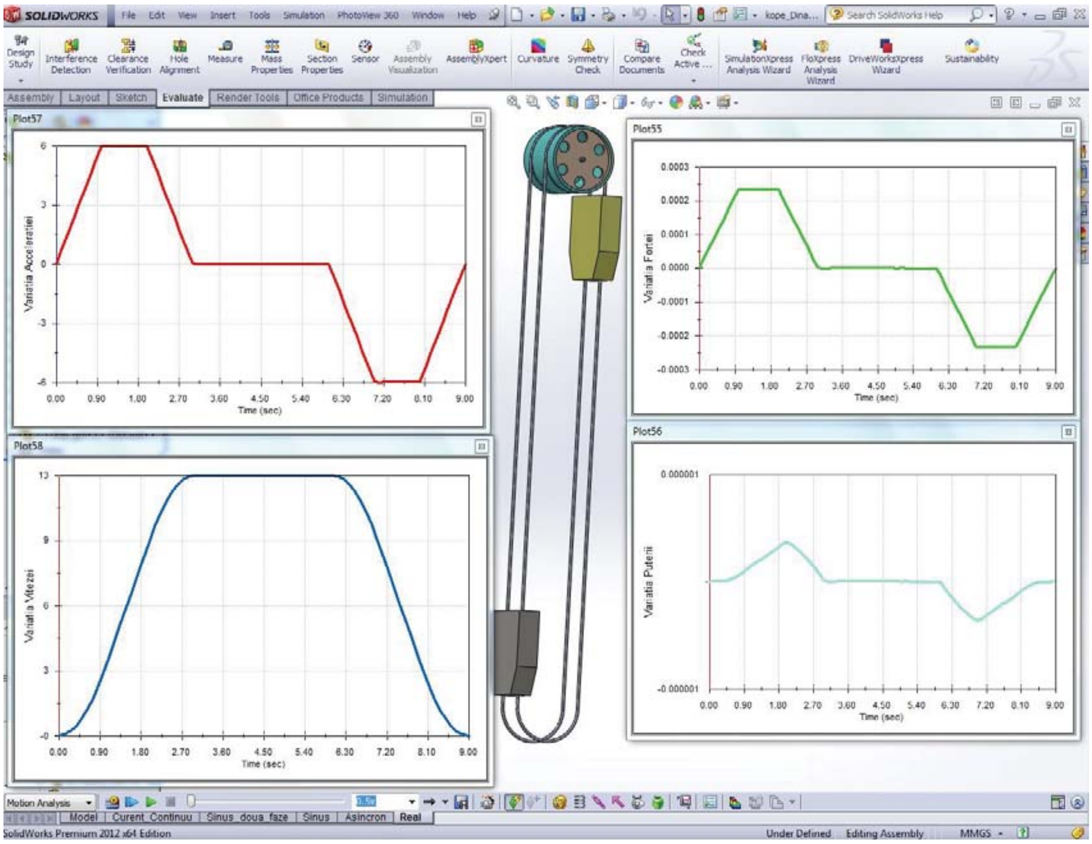

Fig. 10 *Variation of force and power for three-stage tachogram with trapezoidal acceleration variation*

5. Conclusions

Knowing the force values for every tachogram stage allows for determination of actual force and, implicitly, actual power. The actual power value is the measure that imposes the power choice for the actuation engine.

Determining force values at the periphery of the drive wheel using SolidWorks® is a computer-assisted simulation method. The starting point in order to reach the present objective was an assembly-type graphic model. The drive component of the assembly – the drive wheel, in our case – is run by an actuator upon which motion according to variation mode can be applied. Simultaneously, gravitational acceleration acts upon the assembly, thus allowing the calculation model to take suspended and unbalanced masses into consideration.

Following the assessment of the results achieved by application of numerical methods, it is ascertained that they are comparable to those deriving from analytic calculation methods.

The advantages of numerical methods are: possibility of performing a high number of 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 acceleration variation.

Considering the content of the present study, it can be concluded that SolidWorks® software program, besides being an instrument for graphics generation, is also suitable for design and simulation procedures.

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