'Open Ended' Laboratory to Study the Influence of Unit's Weight on Axle Torque in Railway Traction

Petropol Şerb Gabriela Dana[*], Petropol Şerb Ion[†]

[*] University of Craiova/ Faculty of Electrical Engineering, Craiova, Romania, gpetropol@em.ucv.ro
[†] SC RELOC SA, Craiova, Romania, ionpetropol@yahoo.com

Abstract – **The aim of the paper is to propose a scenario and a test bench to study, in a trans-disciplinary way, how the operation of a traction unit with asynchronous motor is influenced by the railway channel. The main issue of the experiment is to find how the weight of the motor unit can influence the axle torque. The topics involved are: 1. 'How to calculate the train resistance to forward movement' (expected results: calculation and plot in Matlab) and 2. 'How to calculate the force needed to move the train and the traction characteristic at the startup of the train' (expected results: data acquisition and plotting in LabView). The design of the scenario follows the guideline of an 'Open Ended' laboratory. The advantages of this approach are: the study can have an inter- and trans- disciplinary approach, the lab could be developed in a hybrid way: in presence in lab, individual for theoretical research and in team to solve and disseminate the results. Regarding IT communication, the research needs to use different software packages as Matlab, LabView.**

Cuvinte cheie: laborator cu caracter deschis, rezistenta la inaintare a trenului, caracteristica de tractiune la demarare a unitatii motoare cu motoare asincrone.

Keywords: *open ended laboratory, the forward resistance to train movement, traction characteristic at start of the motor unit with asynchronous motors.*

I. INTRODUCTION

According to the literature [5], [7], [8], [10] the analysis of some functional aspects specific to the "asynchronous traction motor – railway traction chain" system shows that, during the start-up period, it is observed that:

- the speed changes in the interval $[0, v_a]$, where v_a is the speed corresponding to the calculation regime and represents the speed up to which the adhesion can be used.
- the frequency changes in the interval $[f_p, f_a]$, where f_a is the frequency corresponding to the speed of the calculation regime, v_a, and f_n the frequency at which the train is detached (starting frequency).
- the vehicle must operate on families of traction characteristics which depend on the total mass of the train, m_t, grip and track slope, i.
- starting can be studied for the following types of characteristics (fig. 1), [13]: starting at the adhesion limit (curve 1), starting at constant traction force (curve 2) and starting at constant acceleration (curve 3).

In order to capture as many functional aspects of the asynchronous motor as possible operating under conditions specific to electric traction, an 'open ended laboratory' type

experiment [11], [12] is proposed which will be carried out in several stages, each responding to a well-established objective. Data obtained by data acquisition will be synthesized and processed during the period (2 weeks) of the experiment. As input data for the determination and graphical representation of the electromagnetic torque (a main parameter of the study) it is necessary to determine the parameters of the working machine and to make a specific calculation diagram in Lab View.
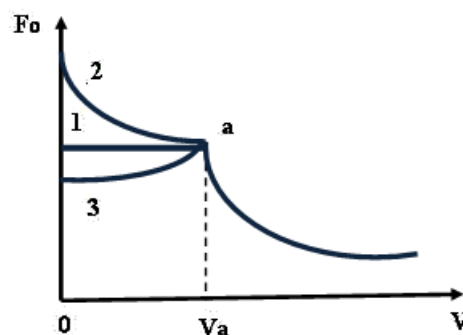

Fig. 1. Possible shapes of the traction characteristic at start-up: starting at the grip limit (curve 1), starting at constant traction force (curve 2) and starting at constant acceleration (curve 3)

II. RESEARCH APROACH

A. *Starting the railway traction vehicle. Mechanical simulation of the maximum traction effort*

In order to capture, in conditions as close as possible to reality, the phenomenon of detachment of the drive unit at start-up, it is proposed to mechanically achieve a torque resistant to the asynchronous motor shaft to simulate the initial frictions 'wheel-track', respectively to highlighting the constant term 'a' in the formula for resistance to advance.

1) Finding the forward resistance to train movement: for a moving train, the determination of the forward resistance has been the subject of numerous measurements which have led to the most general empirical formulas (1).

$$R_p = a + bv + cv^2 \qquad (1).$$

In a first approximation, the constant term a, sometimes called pure slip, depends only on the axle load. It expresses the sliding of the wheel on the rail and bearing. The coefficient b only takes into account the quality of the track and the stability of the convoy. The coefficient c, which naturally represents the aerodynamic part, differs only if the train travels in the

open air or in the tunnel, increasing significantly when passing from one sequence to another, this passage being a function of the piston effect. It is particularly influenced by the aerodynamic quality of the convoy: the front shape, the interval between vehicles, the side roughness, the roughness above and below the body. Except for the fixed form convoy (TGV; Rae; TEEII), where it was possible to measure accurately, this formula remains very approximate.

Table 1 presents some useful formulas for calculating the main forward resistance R_p [N / t] where v [m / s] is the travel speed, S_F [m^2] - area of the front surface of the vehicle, m[t] - mass vehicle, and in figures 2,3 their representation in Matlab.

The general formulas, applied to variable shape trains, highlight its mass. This can be exemplified in the case of a locomotive with n axles.

$$R_p = (0.65 \cdot 10^{-3} + 13\frac{n}{m} + 0.036 \cdot 10^{-3} v + 0.39\frac{v^2}{m}) \cdot mg \quad (2)$$

TABLE 1:
CALCULATION FORMULAS FOR THE MAIN FORWARD RESISTANCES R_p.

| No	Type of rolling stock	R_p[N/t]
	Formulas used by C.F.R., v [m/s]	
1.	Locomotive C'$_0$C'$_0$	$12.3+0.353v+0.0318v^2$
2.	Locomotive B'$_0$B'$_0$	$12.3+0.353v+0.0477v^2$
3.	Passenger wagons	$19,6+0.0397v^2$
4.	Specialized freight wagons	$15,7+0.0471v^2$
5.	Different freight wagons, loaded	$19,6+0.0652v^2$
	Formulas used by S.N.C.F. , v [km/h]	
6.	Locomotive CFF de 120t: Ae 6/6	$35 + 0,06v + 0,59(v/10)^2$
7.	Locomotive de 80t: BB 9001	$13+0,1v+0,375(v/10)^2$
8.	Locomotive de 120t: CC 6001	$12,5 + 0,1v + 0,25(v/10)^2$
9.	Locomotive CFF de 93 t: Am 4/6	$35 +0,4(v/10+ 1,2)^2$
10.	TGV	$2540+33.44v+0.572v^2$
11.	Freight wagons, specialized material	$15+v^2/400$
12.	Different freight wagons	$15+v^2/160$
	Formulas used by metro builders in Moscow, Sao Paolo / Bucharest	
13.	Subways	$28,5+0,424v+0,089v^2$
14.	Subways	$24,5+9,234v^2/m$
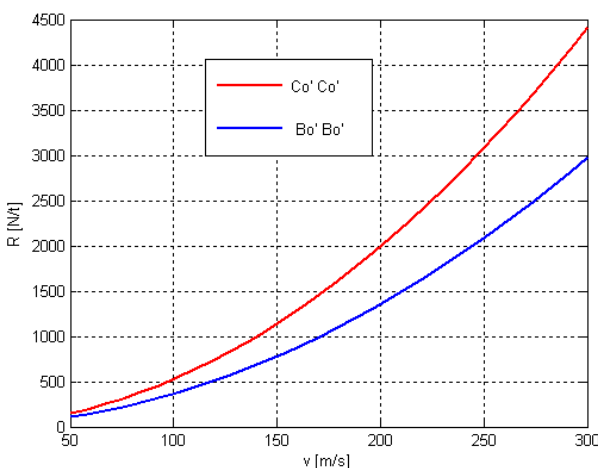
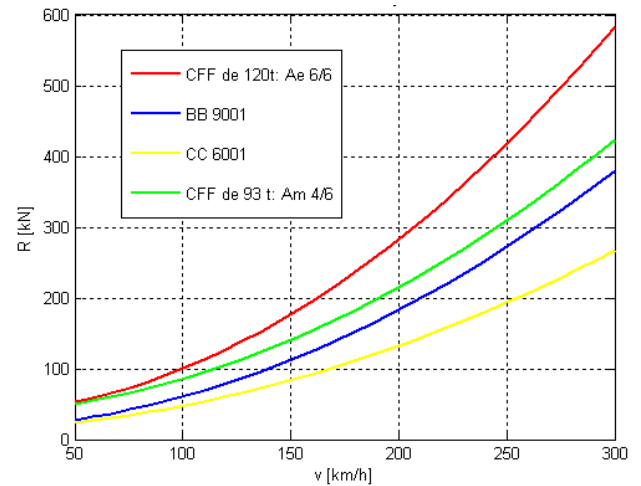Fig.2. Resistances versus speed for Romanian locomotives (plots in Matlab)

Fig.3. Resistances versus speed for SNCF locomotives (plots in Matlab)

For towed trains, without traction motors included, we can cite the CFF formula for freight trains (3) or the general Strahl formula (4) (table 2) [3], [4].

$$R_p = (1.5 + 0.011v + 7 \cdot 10^{-3} v^2)10^{-3} mg, [N] \quad (3)$$

$$R_p = (2.5 + k_t (v + v_v)^2 \cdot 10^{-3})10^{-3} mg, [N] \quad (4)$$

where v_v is the average wind speed (10-15km / h) and k_t coefficient that takes into account the type of train (table 2).

TABLE 2:
COEFFICIENTS THAT TAKE INTO ACCOUNT THE TYPE OF TRAIN ACCORDING TO STRAHL'S FORMULA.

Coefficient k_t		The type of train
[h^2/km^2]	[s^2/m^2]	
0.25	3.2	a. express, direct, heavy freight train
0.33	4.2	b. classic passenger train
0.4	5.1	c. specialized freight train
0.5	6.5	d. compose freight train
1	13	e. empty freight train

Graphs and formulas are usually given for the current running regime. At start-up, after a longer parking of the vehicle (over 20 minutes) the main forward resistance is higher in the first moments (until the wheels make 1.5-2 rotations) than the one resulting from these graphs or formulas for v = 0. It is zero for all other speeds. The starting force is present only at very low speeds; therefore it can be calculated with relation 4.

$$F_a = 7.5 \cdot 10^{-3} \cdot m \cdot g \quad (4)$$

In the literature, [7], [8], [13], the starting torque is determined, depending on the characteristics of the vehicle, by the relation (5):

$$M_{m\,max} = \frac{F_{m\,max} \cdot D_{med}}{2 \cdot i_a}, [kNm] \quad (5)$$

where F_{mmax} is the maximum traction force developed by the engine, D_{med}, is the average wheel diameter, [m], i_a, the gear ratio of the gear.

On another scale, given the direct proportionality between the traction force and the electromechanical torque, we can say that it is confirmed that the traction force required at starting (6) is proportional to the mass of the drive unit.

$$F_p = G_t \cdot \left(r_p \pm i + \frac{1}{\varphi} \cdot \frac{dv}{dt} \right), \qquad (6)$$

where: G_t, is the total weight of the train in kN; $(1/\varphi) \cdot (dv/dt)$ is the specific inertia force that can be set for an acceleration of 0.2 - 0.6 m / s2; φ represents the acceleration imprinted on the train by a force of 1N / kN.

2) Conception of the experimental situation

In the experiment, the technical solution to achieve this enounced dependence is to place a grooved pulley (FR - figure 4) at the free end of the asynchronous machine shaft. The pulley channel will allow the suspension through a steel cable of a variable weight (figure 4) which represents, on another scale, the weight of the motor unit considered.
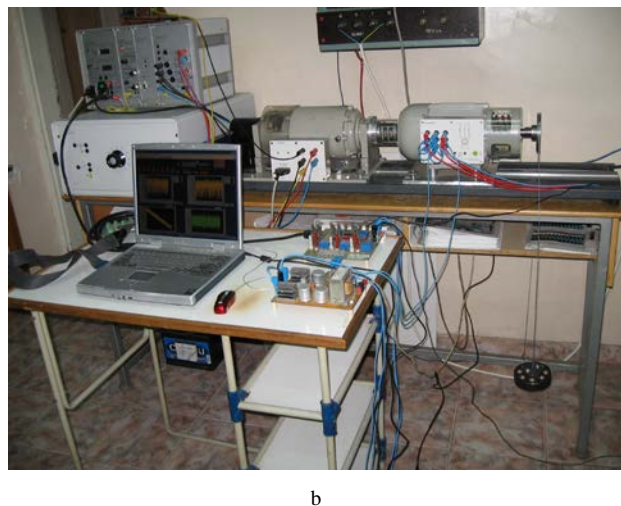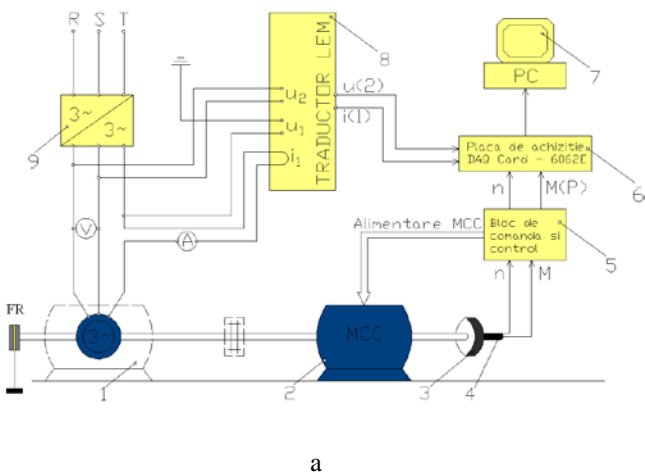

a

b

Fig.4. Experimental test bench with the application of the mechanical brake: a. schematic diagram; b. general view

In this way, the process of detaching the drive unit at start-up will be simulated as close as possible to real conditions. To

vary the starting load, toroidal steel weights with a mass of: 0.5, 1, 2 and 3 kg were made, with the help of which the desired load parameter can be set. Several experimental situations were imagined.

3). Realization of the experimental situation: Asynchronous motor operation powered by a frequency inverter with rated voltage Un = 400V and frequency fn = 50Hz, for different braking weights, m = ct.

In order to determine the influence of the weight of the 'drive unit' on the shaft torque in the case of asynchronous motor powered with rated voltage Un = 400V and frequency fn = 50Hz, the aim is to trace the families of natural mechanical characteristics M (n) for different weights placed on the shaft on pulley.

The practical realization of this experiment involves:

- torque control of the brake machine to ensure a variable torque variable $M_r = 0 - 7$ Nm,

- put one by one, on pulley the different weights (m = 0.5; 1; 2; 3 kg);

- supply of the asynchronous motor with nominal voltage, at the nominal frequency.

4). Processing of experimental data

The quantities of interest (speed and mechanical torque at the shaft, supply voltage and current) are purchased using the acquisition board. To visualize the variation of the shaft torque according to the shaft speed, the diagram in figure 5 will be used.
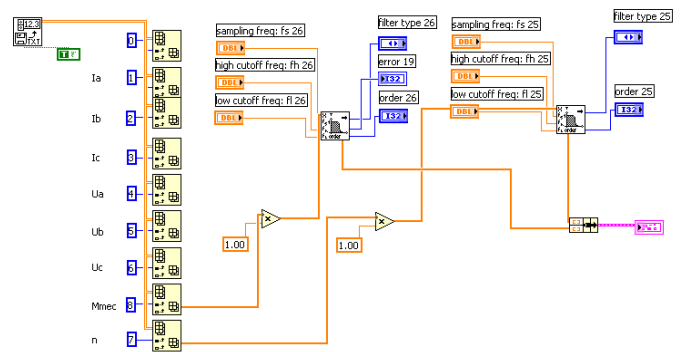

Fig.5. Diagram for visualizing the torque variation at the shaft as a function of speed

III. Simulations and results

The proposed experiment is the starting point to elaborate a learning scenario for an 'open ended' laboratory around the topic: How the weight of the motor unit can influence the axle torque? The aim of this scenario is to connect the students around this subject, to immerse the students in a learning experience that allow them to discuss the problem and to gain high order thinking skills from following the solution. This scenario could be a modern method to use e – techniques in electrical engineering learning. As in [11], a flow chart could be proposed to debate the scenario of the problem.

The experiment was repeated for different weights placed at the free end of the cable and by further processing in Lab View the families of characteristics in figure 6 were obtained.
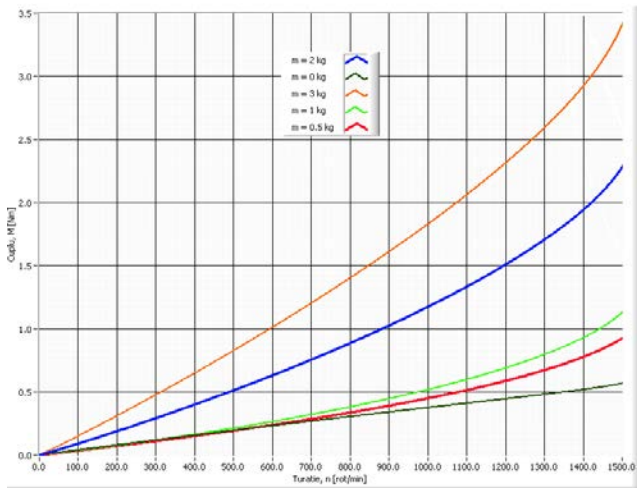
Fig.6. Family of characteristics M (n) for m = ct, M_r = 0 - 7 Nm, U = 400 V, f = 50Hz.

From the study of the family of characteristics it is observed, as expected, that at the same speed (for example n = 1400 rpm), the torque required at the shaft is higher for a higher braking mass (m = 0kg, M = 0.51 Nm; m = 0.5kg, M = 0.82 Nm; m = 1kg, M = 0.99 Nm; m = 2kg, M = 1.93 Nm; m = 3kg, M = 2.94 Nm;). Therefore, the higher the mass of the vehicle, the higher the torque at the required shaft and therefore the starting torque.

Following the evolution of the speed in the two cases (m = 0 kg, m = 3kg) it is observed that this is also influenced by the presence of the weight at the end of the pulley.
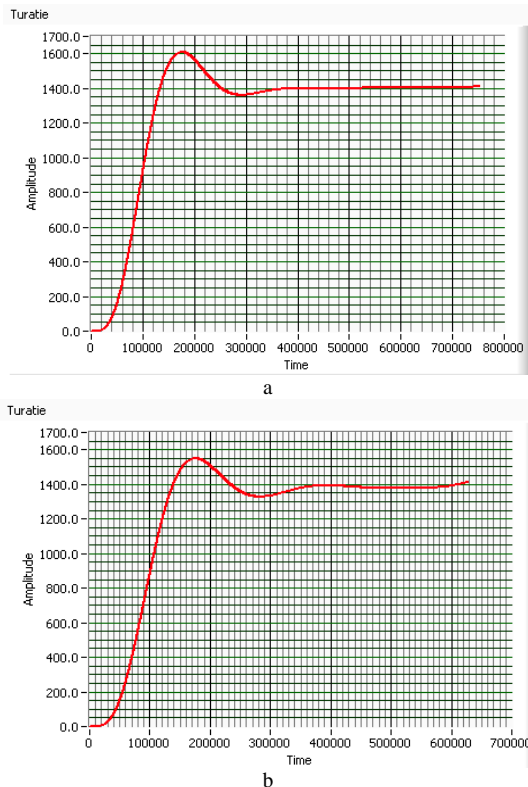

a

b

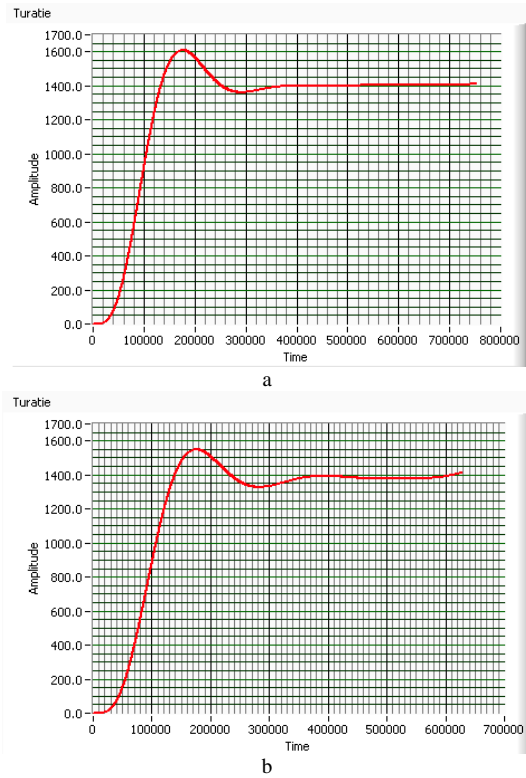Fig.7. Variation of asynchronous motor speed over time, n (t), in cases where the braking mass is: a. M = 0kg, b. M = 3kg

a

b

Fig.8. Time variation of the mechanical torque at the asynchronous motor shaft, in cases where the braking mass is: m = 0kg; b. m = 3kg.

Figures 7 and 8 show the time variation of the speed and the mechanical torque at the shaft, under the conditions of operation on the natural mechanical characteristic without a braking mass, m = 0kg (fig. 7a, fig. 8a), respectively on the natural mechanical characteristic (fig. 7b, fig. 8b) if the braking mass is m = 3 kg.

There are different time intervals to reach the stationary value of the torque (lower in case of a higher braking weight), as well as the oscillations of the speed and torque in the first moments of starting, after which both the speed and the torque reach the values stationary.

In order to observe the variation of the torque at the shaft in case of variable frequency starting (f = 0 - 50 Hz), as well as the effect of the braking weight on this variation, we aim to trace the families of characteristics M (n) for different weights placed at the end of the brake cable. mechanical.

The practical realization of this experiment involves:
- constant torque control of the brake machine;
- suspending in turn, at the end of the pulley cable, the different weights;
- starting the asynchronous motor with variable frequency, on frequency characteristics (f = 0 - 50 Hz).

In order to observe the influence of the starting frequency on the value of the shaft torque, repeated starts of the asynchronous motor with different starting frequencies for the same weight of the motor unit will be performed. The tracing of the families of characteristics M (n) will be followed.

The practical realization of this experiment involves:
- torque control of the brake machine to ensure a variable torque variable Mr = 0 - 7 Nm,
- suspension in turn, on pulley, of different weights;

- starting the asynchronous motor with variable starting frequencies (increasing from 10 to 10 Hz);

- The purchase of the quantities of interest (speed and mechanical torque at the shaft, voltage and supply current) is made with the help of the acquisition board.

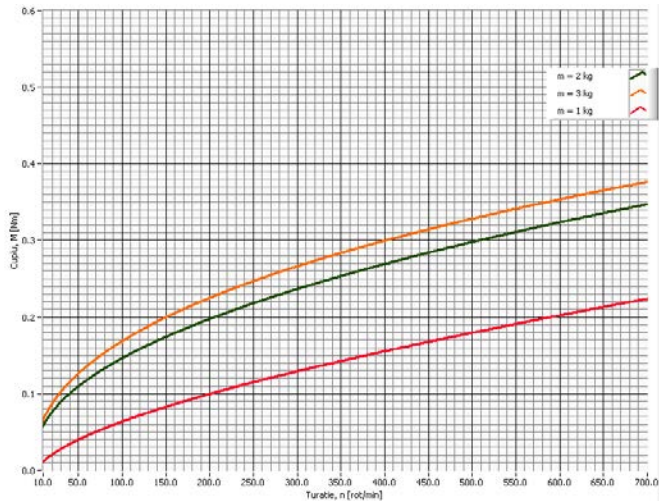Subsequent processing in Lab View yields the feature families in figure 9 for a starting frequency fp = 50Hz.

Fig.9. Family of starting characteristics M (n) for starting frequency f = 50Hz and braking masses m = 1; 2 and 3 kg.

Figure 9 shows that, for the same starting frequency, the initial value of the torque is higher for a higher braking mass.

Figures 10 and 11 show the same variations for the frequencies of 30 Hz and 20 Hz, respectively.

Comparing figures 9, 10 and 11, which represent the family of starting characteristics with constant frequency and different braking masses, it is observed once again that, for the same starting frequency, the initial torque value is higher for a higher braking mass is big.
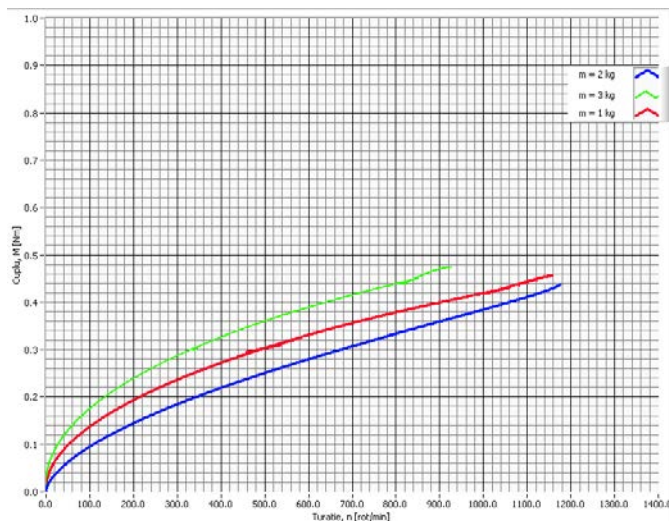

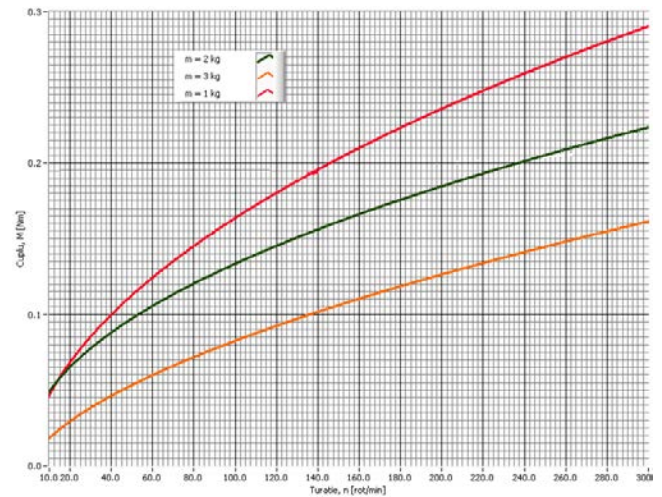Fig.10. Family of starting characteristics M (n) for starting frequency f = 30Hz and braking masses m = 1; 2 and 3 kg.

Fig.11. Family of starting characteristics M (n) for starting frequency f = 20Hz and braking masses m = 1; 2 and 3 kg.

During the experiments, in addition to the mechanical quantities, the torque and speed of the machine shaft and the values of stator currents and voltages were acquired. With the help of these data direct observations can be made on the behavior of the asynchronous traction motor. The variation in time of these quantities, in the situations presented in the experiment, can be visualized with the help of a block diagram made by LabView, similar to the one in figure 5.

IV. CONCLUSIONS

The paper proposes a learning tool to study different practical situation which are involving a traction motor unit with asynchronous motor.

Proposing and realizing experimental situations, the paper show how the acquired data could be implement using numerical method to calculate different characteristics of an asynchronous motor. These results could be easier applied in different practical situation or learning scenarios.

An important advantage of this proposal is that the study could be made in a hybrid mode both in presence as in online (an important feature of our days).

It also responds to an actual context of industrial environment and educational background characterized by translating into computer mode all data, aimed to increase the efficiency and the quality of process.

This paper is a response to the need of organized the knowledge in an authentic and resourceful form to be effortless applies to improve the understanding of operating the electromechanical systems.

Contribution of authors:

First author – 60%

First coauthor – 40%

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