ELECTRICAL ACTUATION OF THE GRINDER OF AN AUTOMATED COFFEE

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Abstract: *The paper refers to espresso coffee machines high quality and some possibilities to increase the level of automation and productivity, while the designed PV system ensures the independence to the machine from the grid power. Existing machines require manual adjustment of coffee grinder depending on the quality of coffee beans. To eliminate this flaw an adjustable electromechanical system with DC servomotor and numerical control of coffee grinder has been developed and implemented. Computer simulation results demonstrate the functionality of the proposed electromechanical drive system of the coffee grinder.*

Keywords*: coffee machines, electromechanical system, DC servomotor, numerical control*

INTRODUCTION

Coffee maker is one appliance the can be seen nearly in every home and office, as society has embraced coffee as a new human necessity. Coffee machines [1, 2, 3] have begun to become incredibly complex due to the technological development and the accessibility of automating devices. The increased level of sophistication of the coffee machine provides a better coffee brewing, and as a result, a higher quality beverages for a smaller cost.

Purpose of the work consists in developing an electromechanical automated adjustment system of the grinder to the quality of coffee beans.

1. Coffee extraction methods in modern coffee machines

There are many methods for brewing a fine cup of coffee and no single technique is right for everyone. The most popular variation of the pressurized percolation brewing is the coffee called espresso. After lots of experimentation, Luigi Bezzera came up to some exact figures for extracting the perfect shot of espresso. These technical parameters that have been outlined by the Italian Espresso National Institute [1] (**tab. 1**).

Table 1. The technical parameters for making the Certified Italian Espresso

ELEMENT	PARAMETER
Portion of ground coffee	7.0 g ± 0.5
Exit temperature of water	90ºC ± 3ºC
Temperature in cup	67ºC ± 3ºC
Entry water pressure	9 bar ± 1
Percolation time	25 sec. ± 5
Volume in cup (including froth)	30 ml ± 2.5

Taking these parameters and the technical possibilities of modern days into consideration there can be outlined three types of extracting technics:

1. Extraction with non-pressurized portafilter – this type of portafilters have no outlet valve inside them that can control the appropriate 9 bar pressure for extracting the espresso in wright conditions. The appropriate adjustments are made with the fineness of the grounded coffee.
2. Extraction with pressurized portafilter – these portafilters have a system inside them in the form of an outlet valve that controls the pressure inside and keep the 9 bar no matter the fineness of the ground coffee.
3. Extraction with brewing unit. In 1986 SAECO Company introduced the brewing unit for the first time [2]. The unit gives the possibility to automate the brewing process completely. It makes four very important actions while brewing:
   a. It receives the grinded coffee from the dozer,

b. Compresses the coffee into the brewing capsule with the appropriate force,
c. Runs the 92ºC water through the coffee capsule with the 9 bar pressure controlled by the outlet valve that is incorporate in the unit.
d. Throws the used coffee into the dregs drawer.

2. The structure of the electromechanical system of the super-automated class of coffee machines

The technology changed a lot from the first invention of a coffee machine ending with one of the most sophisticated class of coffee makers nower days and this is the super-automated machines that have a fully automated process that starts with grinding the beans and finishies with proper extraction of espresso. In the fig. 1 the scheme of such an electromechanical system is represented. As there was mentioned earlier, the hydraulic system must ensure the necessary water and steam characteristics for the proper function. The structure of the system consists of boiler J for brewing and hot water dispensing, and the pipe heater for steam. The necessary pressure of the water is provided by an electromagnetic pump and the right quantity of the water is measured by a turbine flow meter.

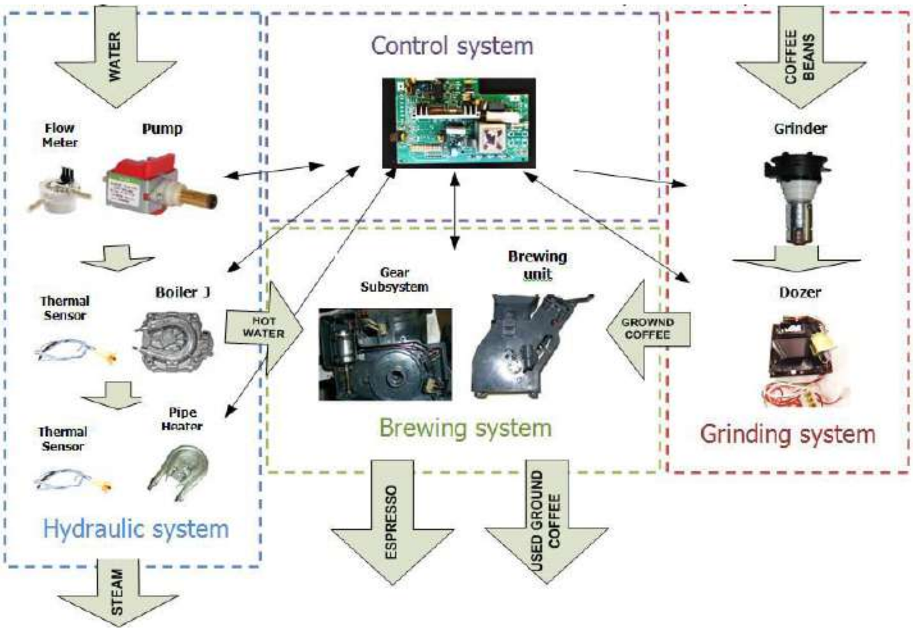


Figure 1. The scheme of the electromechanical super-automated system of the SAECO ROYAL series

By means of the grinding system the coffee beans are grinded and the necessary amount of ground coffee is measured and thrown into the brewing unit and taking into the consideration the manipulations that are necessary for these actions this system consists of the following components:

The hydraulic system [3] must ensure the necessary water and steam characteristics for the machine proper function. The necessary pressure of the water is provided by an electromagnetic pump and the right quantity of the water is measured by a turbine flow meter connected in the low pressure part of the pipe system.

- Dozer – the coffee quantity for the every coffee process is portioned (dosed) in the dozer chamber where a higher dose results in a stronger and more concentrated coffee, and a lower dose results in a weaker one.
- Grinder – is the electrical burr grind that consists of two revolving, conical elements with upper and lower grinding disc. The grind level is set by adjusting the height of the upper grinding disc by means of the screw thread. The grinder has three main components:
  - Grinding discs;
  - Gearbox that reduces the grinding motor rotations with 40:1;
  - DC current, 240V grinding motor.

The brewing system performs a number of very important actions with the grounded coffee that comes from the grinding system.

The whole system of the present coffee machine is controlled by a numerical control system that consists of two electronic boards and a display with a set of buttons for controlling the system.

3. Initial data for photovoltaic power cells calculations.

Considering the total necessary number of espresso cups and the fact that dispensing frequency of then cannot be exactly determent, it is decided to consider one heating stage of about 90 second and a standby mode of about 105 seconds for every 3 cups of espresso. With these numbers in mind the bar graph has been constructed and presented in the **figure 2**.

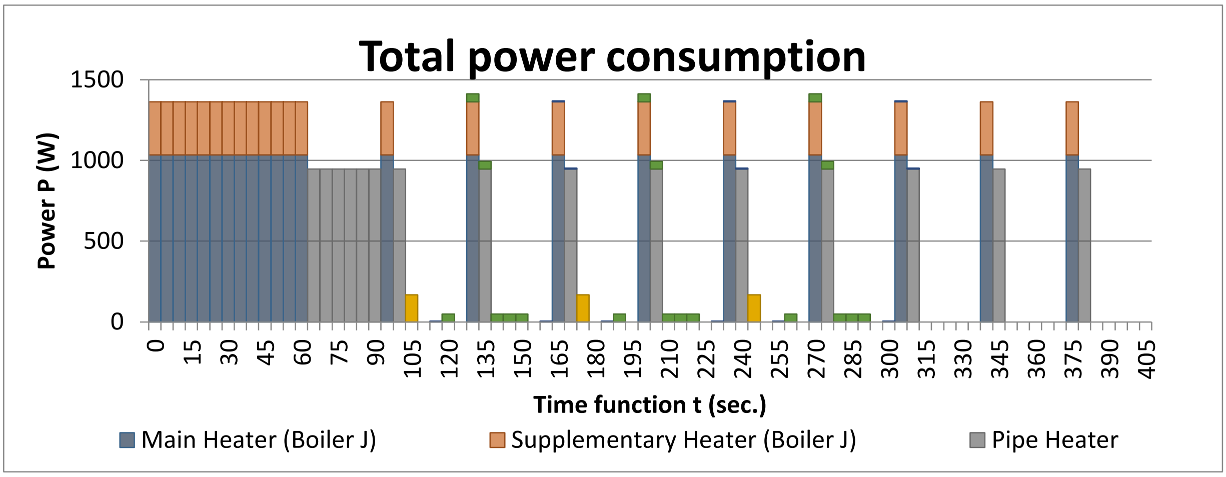


Figure 2. The total power consumption in terms of time function for every three coffee dispensing processes

Diurnal energy consumption calculation.

The diurnal energy consumption will be calculating to production of 100 cup of espresso.

$$E_{405} = \sum_{i=1}^{k} \frac{P_i \cdot t_i}{\eta_{CF} \cdot 3600} = \frac{1034 \cdot 105}{0,9 \cdot 3600} + \frac{330 \cdot 105}{0,9 \cdot 3600} + \frac{946 \cdot 75}{0,9 \cdot 3600} + \\ + \frac{168 \cdot 15}{0,9 \cdot 3600} + \frac{6 \cdot 60}{0,9 \cdot 3600} + \frac{48 \cdot 90}{0,9 \cdot 3600} = 68,32 Wh \quad (1)$$

E_{405} - the energy consumed within 405 sec. of functioning with three production cycles.

$E_c = \frac{E_{405}}{3} \cdot n_c = \frac{68,32}{3} \cdot 100 = 2277,5 Wh$ - required energy for 100 cups of espresso.

Calculation of the solar radiation available on the power cells surface.

Analyzing the representation the weather conditions in the Republic of Moldova it can be concluded that the optimal inclination angle for the central part of the country is $\beta = 32$ [6] which will be taken as the inclination of the photovoltaic power cells for present installation and the functioning annual period is considered from April to October. Further on, the calculations for the April diurnal period of time will be taking into the considerations so that the system will have enough solar energy to function within the whole period of 8 months.

For the month of April $R_\beta = 1.17$ for the 32° angle inclination.

$$B_\beta = B \cdot R_\beta = 0.12 \cdot 1.17 = 0.14 \quad (2)$$

$$D_\beta = 0,5 \cdot (1 + \cos\beta) \cdot D = 0,5 \cdot (1 + 0,85) \cdot 0.24 = \frac{0.22}{3.6} = 0.061 kWh/m^2 = 61 Wh/m^2 \quad (3)$$

The total number of hours per day with the standard solar irradiation that is noted as **HRS** for the month of April (the month with less solar irradiation) is:

$$HRS = 4.44h$$

The calculations of the necessary electric energy for production by the PV cells.

$$E_P = \frac{E_C}{K} = \frac{2277,5}{0.75} = 3036 Wh \quad (4)$$

The critical power of the PV module is determent with the formula:

$$P_c = \frac{E_P}{HRS} = \frac{3036}{4.44} = 683,92Wc \quad (5)$$

The photovoltaic PV power cell of the type CS5A-190 is chosen that is a robust 72 cells solar module. These types of PV modules can be used on-grid and off-grid

Table 2. Electrical and mechanical characteristics of the PV of the type **PV-MLU255HC** [3]

Model Type	PV-MLU255HC
Maximum power rating, (Pmax)	**255 W**
Maximum power voltage, (Vmp)	**31,2 V**
Maximum power current, (Imp)	**8,18 A**

Taking into the consideration the present electrical device that will be powered with the chosen PV cells, the rated current flow in the wires that will connect the photovoltaic power cells, and the M point (maximum power point), it has been considered to have a mixed connection of them with the following number of cell connected in series in order to reduce the spending for wires:

$$U_{PV} = U_{mp} \cdot n_s = 31,2 \cdot 3 = 93,6V \quad (6)$$

The medium diurnal current consumption of the electric load.

$$I_{med} = \frac{E_P}{24 \cdot U_{PV}} = \frac{3036}{24 \cdot 93,6} = 1,35A \quad (7)$$

The PV module current generation:

$$I_{PV} = \frac{24 \cdot I_{med}}{HRS} = \frac{24 \cdot 1,35}{4.44} = 7,31A \quad (8)$$

The number of modules in the series connection.

$$N_p = \frac{I_{PV}}{I_{SC}} = \frac{7,31}{8,89} = 0,82 \approx 1line \quad (9)$$

The capacity of the battery accumulator's calculation

Considering the input voltage for the invertors for transforming the DC current into AC, it is decided to have 24Vdc for SAECO and 48Vdc for ASTORIA in the accumulators DC circuit

$$C = \frac{n \cdot E_c}{K_D \cdot U_{DC}} = \frac{2 \cdot 2277,5}{0.6 \cdot 24} = 316,3Ah \quad (10)$$

The number of battery accumulator's calculation

$$n_{bat} = \frac{C}{n_{pl}} = \frac{316,3}{3} = 105,53 \approx 110 \, {}^{Ah}\!/_{line} \quad (11)$$

According to the obtained results, 6 batteries are selected with the standard capacity of 110 Ah of deep cycle technology with the price of 3200MDL that will be connected in three parallel lines with two batteries in every line in order to obtain the necessary 24V in the DC battery circuit.

Electrical energy balance verification.

The verification of the consumption balance of the electrical energy for the month with the weakest solar irradiation - $HRS = 4.44h$ with the standard irradiation.

The energy produced by the PV modules during a day:

$$E_K = HRS \cdot P_{PV} = 4.44 \cdot 3 \cdot 255 = 3396,6Wh/day \quad (12)$$

Comparing the electrical energy necessary and the electrical energy produces by the PV module we can ensure that the energy obtained from the PV modules is enough for the normal functioning of the coffee machine within the whole period of time from April to October.

$$E_K = 3396,6Wh/day > E_C = 2277,5Wh/day \quad (13)$$

and in this case the level of discharging of the batteries will be calculated:

$$K_D = \frac{E_C}{U_{CC} \cdot C_{AC}} = \frac{2277,5}{24 \cdot 3 \cdot 110} = 0,287 \quad (14)$$

Photovoltaic solar system charge controller selection

The photovoltaic solar system controller is a very important component. It divides the voltages of the three different branches: the PV cells voltage accumulator, batteries voltage and the invertor input voltage, and has a number to functions that are presented in the following list:

- Monitors the available power ether from the PV cells or from the batteries;
- Monitors the charging level of the accumulator batteries and charges theme when the extra power is available;
- The most performant solar controllers have the Maximum Power Point Tracking function that keep the consumption load at the M point characteristics.

4. Modernization of the grinder's adjustment system of the coffee machine

The components and the control system of the present automated coffee machine can provide the necessary quality of the water temperature, pressure, flow rate and the duration of the percolation process, but the grinding process remains automatically nonadjustable and it can be concluded that the system is not fully automated and that the need of a technical operator would be necessary every time when the quality of the coffee beans would change. The quality of the coffee bean is determined by a number of factors that have an influence on the grinding process, and consequently, on the quality of the extracted beverage. These factors are very numerous, divorce and of different nature and some of them are:

- The grade of coffee
- The humidity level
- The over drying

As it can be concluded, the quality of the coffee beans has a big influence on the level and the duration of the grinding process and in order to modernize the grinder adjustment system it is necessary to understand the influence of coffee bean with different qualities on the rest of system's components which are presented in the following list:

- Pump – the grinding level influences the hydraulic system and especially the flow rate of the pump and the necessary pressure for the water to pass through the packed grounded coffee in the brewing unit chamber.
- Grinding – the coffee fraction size influences the duration of grinding time. The smaller the fraction of the ground coffee the longer the grinding time.

Taking into the consideration the influences of the coffee fraction size enumerated above, the only parameter that differs with the same dependency no matter the coffee grade selection, or the quality of it, is the flow rate of the water during the brewing process. This control can be performed directly, by controlling the actual flow rate with the hydraulic system's flow meter, or indirectly by controlling the current that is passing through the pump. The easiest and the most exact solution would be the direct control of the flow rate.

In order to adjust the grinding discs and to move the upper disc up for a coarser grinding and down for a finer grinding it is necessary to move the adjustment ring on the grinder (fig. 3) in a clockwise direction for a finer grind and anticlockwise for a coarser grind.

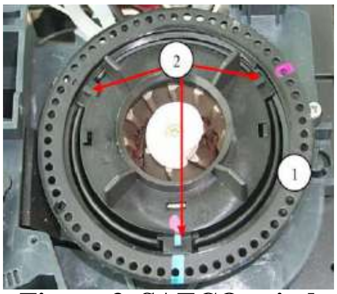


Figure 3. SAECO grinder
1 – adjustment ring
2 – three fitting lugs of the upper grinding disc

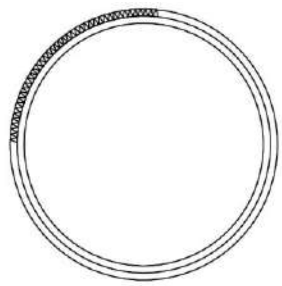


Figure 4. The cogwheel of the automated adjustment

Taking into the consideration the necessary adjustment steps and the fact that this is the only possible procedure for the adjustment of the grinding system, the automated adjustment system has to repeat them and for that some modifications has to be done on the grinding system so that it could repeat them. In the fig. 5 the structural scheme of the grinding system is represented where the proposed adjustment system is showed.

The necessary modifications are:

1. A cogwheel has to be mounted on the grinder's adjustment ring in order to give the automated adjustment system the possibility to turn the adjustment ring (fig.4). Considering the dimensions of the adjustment ring the total number of teeth on the cog ring would be 180 with 1 tooth for every 2º.

2. A servomotor has to be added in the adjustment system that would provide the necessary movement of the adjustment ring. Considering the fact that the ring needs to be moved in both directions, it is decided to choose a DC servomotor which provides an easy way to change the rotation of it by changing the polarity of the connection. In order to dimension the parameters of the necessary DC motor a number of calculations are required

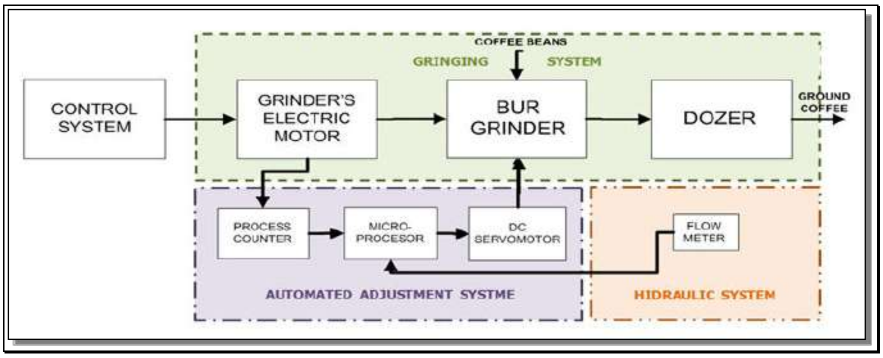


Figure 5. The scheme of the electromechanical system of the grinder

$t_{ad} = 1\sec$ - the time of a single adjustment; $D_{ar} = 95mm$ - the diameter of the adjustment ring; $D_{sh} = 38mm$ - the diameter of the cogwheel on the shaft of the motor; $L_b \le 10mm$ - the length of a single adjustment; $L_{ar} = D_{ar} \cdot \pi = 95 \cdot \pi = 298,3mm$ - length of the adjustment ring;

$V_{ad} = \frac{L_b \cdot 60}{t_{ad}} = \frac{10 \cdot 60}{3} = 200 \, {}^{mm}\!/_{\min}$ - velocity of the adjustment movement;

$$L_{sh} = D_{sh} \cdot \pi = 38 \cdot 3,14 = 119,4mm \qquad (15)$$

$$\varpi_c = \frac{V_{ad}}{L_{sh}} = \frac{200}{119,4} = 1,68 \, {}^{rot}\!/_{\min} \qquad (16)$$

Based on the calculations above, a reversible servo DC motor of the type MH – 145 Б is chosen and is represented in the (fig. 7) along with the technical parameters of it [4].

U_n=27 V.DC	n_r=145 rot/min
I_n=0,6 A	η=25%
P_n=2,45 W	M_n=1,69 kg/cm

Figure 6. DC servo motor of the type MH – 145 Б

The selected servo motor provides the necessary velocity for the movement of the ring and the adjusting time would be 1 sec.

5. MATLAB simulation of the grinder adjustment system

Taking into the consideration the fact that the simulation software gives us a good possibility to analyze the performed calculations without spending any money for the actual components it was decided to simulate the work of the servomotor with all the reducers in order to check the system functioning during the adjustment movements. For this simulation the MATLAB SIMULINC software will be used with its SimPowerSystems library pack.

- The initial parameter of the chosen servomotor provided by the manufacturer:

$MH - 145Б$ - Motor code;

$i = 10:1$ - Gear ratio;

$U_n = 27Vdc$ - Nominal voltage;

$n_r = 145rot/\min$ - Nominal speed

$I_n = 0,6A$ - Rated current;

$P_n = 2,45W$ - Rated power;

$\eta = 25\%$ - Efficiency;

$R_a = 16,7\Omega; L_a = 1H;$

$R_f = 136,5\Omega; L_f = 70H;$

- Calculated parameters of the DC motor
  - Nominal angular rotor speed, rad/sec

$$\varpi_n = \frac{2\pi \cdot n_n \cdot i}{60} = \frac{2\pi \cdot 145 \cdot 10}{60} = 151,8 rad/s \quad (17)$$

  - Nominal torque, N*m

$$M_n = \frac{P_n}{\varpi_n} = \frac{2,45}{151,8} = 0,0161 N \cdot m \quad (18)$$

To study the operation of modernized coffee grinder was developed the mathematical model of electromechanical systems in accordance with the corresponding relations of the components [5]. The Simulik model (fig.7) include blocks of the DC motor, Speed Reducer and the cogwheel to the adjustment ring with the specific parameters.

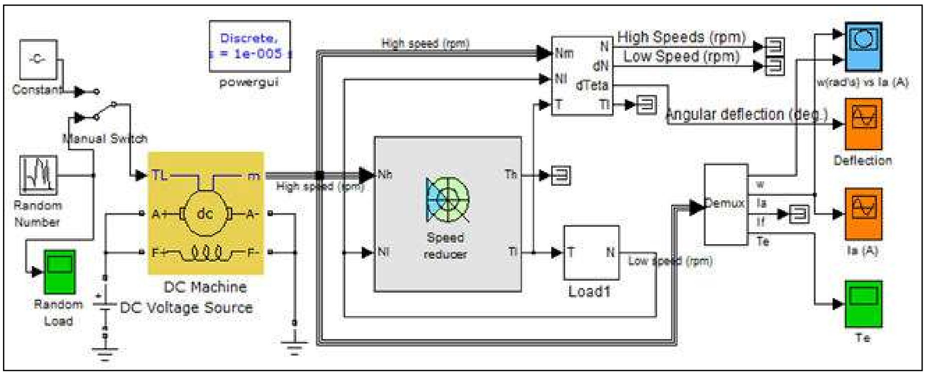
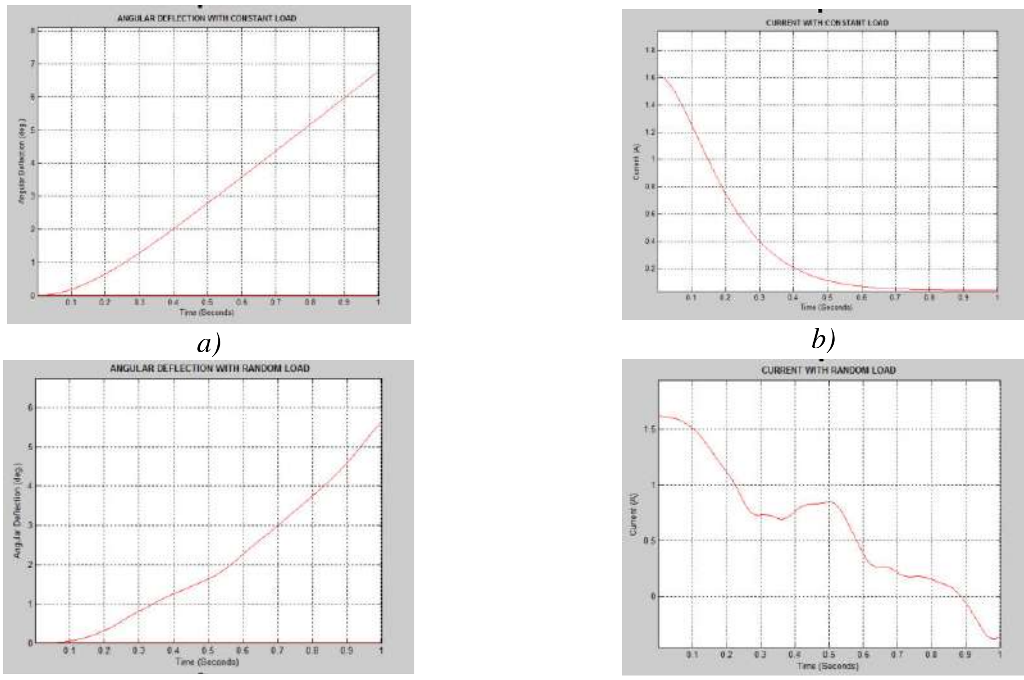


Figure 7. Adjustment system DC motor speed reducer simulation

The simulation was performed with two different load: with the constant load and with the random load that would represent the different quality of coffee beans during the grinding process. After the performed simulation the results of the modeling are displayed by the scope of the present model. The scope representations are given in the fig. 8 for the constant and random loads on the grinder. The simulation showed that even with random load on the grinder the angular deflection within 1-2 seconds is quite enough for the adjustment proccess.



a) b)

c) d)

Figure 8. The results of the DC motor speed reducer simulation in the SimPowerSystems

a – angular deflection of the adjustment ring of the grinder with constant load;

b – armature current of the DC servomotor of the adjustment system with constant load;

a – angular deflection of the adjustment ring of the grinder with random load;

b – armature current of the DC servomotor of the adjustment system with random load.

CONCLUSIONS

As a conclusion to the present work, it can be mentioned that the automated adjustment system can provide the necessary settings and adjustments for the espresso machine so as to get the most of the coffee beans and for that the following actions have been performed:

1. The inclination of 32º for the PV cell allow the system to provide the necessary energy for the all the equipment to work between the mentis of April to October;
2. The presence of batteries in the system allows the normal functioning for 4 days with medium nebulosity;
3. Have been considered and reasoned the necessity for the adjustment system.
4. The proper possibility have been chosen and proposed.
5. A DC motor has been chosen and the speed reduced has been calculated.
6. It was proposed the possibility of using a micropressesor for the automation performance in case if it will not be possible to get a SAECO Programmer to reprogram the SAECO DIGITAL CONTROL SYSTEM.
7. A simulation has been designed and performed in order to analyze and check the chosen components; the electric motor and the speed reducer. The simulation showed that even with random load on the grinder the angular deflection within 1-2 seconds is quite enough for the adjustment process.

The designed automated adjustment system can be used as a separate intermediant divise between a poffesional grinder and a proffesional coffee machine in order to provide the best quality of the coffee beverage.

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