Study of Speed Control of Direct Current Machine with Separate Excitation Torque Control

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Abstract— *This work focuses on the study of the speed control of a DC machine with separate excitation with torque control in order to regulate the speed of the latter. Forcing the output of a system to follow a prescribed trajectory, despite the hostility of a disturbing environment rarely achieved by a unique structure of the control loop. Therefore, it is generally used a structure also capable of implementing a suitable controller. To avoid a theoretical study, we developed a cruise control. This unidirectional and irreversible regulator has two cards namely the control board and the power. These two cards are fed into summer's regulation chain. The measurements allowed us to high light the characteristics and performance of the speed controller studied.*

Index Terms— *Control, Cruise Control, Torque Control, Control, Performance.*

1 INTRODUCTION

The industry in the broad sense and transport have increasingly need to continuously variable speed system, endowed with flexibility and precision. It is true that the mechanical and hydraulic solutions are still used, but electrical solutions are most appreciated today by far. Their success comes from the incomparable characteristics that give those electronics, both in terms of energy conversion than that of the servo system [2]. Moreover, the majority of industrial processes requires the control of a number of parameters such as speed, current, temperature, pressure, to name a few. This is the role assigned to the control channel to maintain predetermined levels, the parameters that govern the operation of the process regardless of the external disruptive elements to which they are subject [1]. This is one reason why the control of electric machines, traditionally provided by electromagnetic components, makes increasing use of electronic equipment, the vector method and in particular to cruise control. Note that vector control, which allows a decoupling between the controls variables used for its high dynamic performance, taking into account the wide range of applications aims to:

- Find how asynchronous motors or permanent magnet DC motors with separate excitation are controlled;

- Go out a natural decoupling between the magnitude controlling the flow (excitation current) and one related to torque (armature current).

Note that the vector control techniques drew their basic idea of the model of the asynchronous motor in the d_q synchronous reference frame. Indeed, the direction of flow in the machine of the axis, and maintaining this constant stream oriented via the direct component of the stator current, adjusts the torque through the quadrature component of the same current, thus achieving the decoupling between the flux and torque in the induction motor. Unlike the DC machine, both components of the stator current ids and iqs are strongly coupled. Position without any change in one of these two currents will produce a disturbance in the other and thus deteriorated the control torque. In recent years, the work on the torque control using vector method have led some authors like Briz *et al.* [1], Boussak and Jarray [2], Harnefors and Nee [3], Comanescu [4], Jung *et al.* [8], Yongchang *et al.* [9], Sutikno *et al.* [11], Vojkan *et al.* [13] and Bhoopendra *et al.* [14]. We also note that new industrial applications require variable speed drives with high dynamic performance. These speed controllers have the following tasks:

- Obtain different approach speeds or adjustment;

- To start or gradually slow an engine according to a given law;

- To enslave or synchronize the operation of a machine.

However, DC motors have as main advantage that the rotational speed of the drive shaft and the voltage at motor terminals are linked by a simple relationship. This allows to easily vary the speed by adjusting the value of this voltage. The DC motor comprises a field circuit disposed on the stator and an armature circuit disposed on the rotor is energized in various ways. The field circuit may be in series with the armature circuit (series motor) in parallel with the armature circuit (shunt motor) and decoupled from the armature circuit (separately excited motor). In addition, the DC motor has all the qualities necessary to operate at variable speed to adjust the speed provided by the supply voltage of the armature. Given the diversity of the field of use of speed governors and the possibilities offered by the latter on an industrial scale in developing countries, it is necessary to conduct a study on the speed control of a DC machine separately excited with torque control. In other words, it is important to analyze the operation of DC variable speed machines in their main field of use. Given all the above we can ask the question: how to determine the operating speed of the DC variable speed machines used in the industrial world? This article in its joints, first presents the material basis and methods which details the study of the speed control

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of a DC machine with separate excitation with torque control, and the title results and discussion this speed control followed by a critical comparison with those devices presented by the literature and finally the conclusion.

2 MATERIALS AND METHODS

2.1 Materials

As part of this work, we used a DC motor, therefore the following characteristics: P = 3 kW; I= 17 A; V_{eff} = 220 V; N_n= 1500 rev/mn and Type c 132 sp, n° 821 278/10, EXC SHUNT, V_{eff} = 220 V, I_{exc} = 0,8 A and Dimensions 10x20x25. This engine is equipped with tachometer generator name plate contains the following information: Type RE_0 444, N° 1173428, Speed constant 0,06 V/tr/mn, I_{max} = 0,18 A and N_{max} = 1000 tr/mn.
We used an oscilloscope PHILIPS brand, model PM3215 band width 50 Hz to see the different timing. A Variac and a stabilized supply brand **Didalab**, 2656 model as sources of tension when trying different we were also useful. Measurements of voltage and current of the armature of our engine is given by a CDAPOLYCA voltmeter 777 and Ampermeter 780 POLYCACDA. We put to a digital tachometer 01-2015, NF5601 of AOIP for measuring the rotational speed of the motor.

2.2 Methods

Because some parameters like the resistance of the armature, the coefficient of self induction and the moment of inertia is not on the motor name plate, it is necessary to determine beforehand. Indeed, these parameters allow us to determine the damping coefficient ξ and the resonance of pulsation ω_n.

2.2.1 Measure of the resistance R of the armature

The volt-ampermetric method is used to determine the resistance R of the armature. The figure below shows this method.

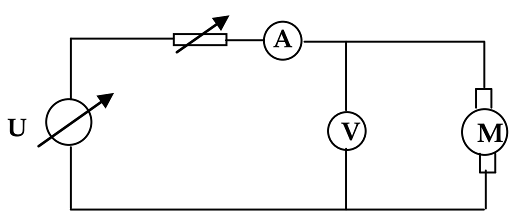

Figure 1: Measuring the resistance induced R by the volt-ampermetric method.

The rotor is carefully blocked, the motor is supplied at reduced voltage so that power from being too far from the rated current.

2.2.1 Measure the coefficient of self-induction *L*

The coefficient of self-induction engines is generally determined by measuring the impedance of the coil supplied with alternating current. Using the figure of method ampermetric-volt, is applied the voltage. A using a variable transformer, the induced current is fixed and there is obtained a voltage across the armature. The impedance Z is given by the following equation:
$Z = U/I = [R^2 + (L\omega)^2]^{1/2}$ avec $\omega = 2\pi f$.

From this relation, we deduce the inductance *L*. There for:
$L = 1/2\pi f\,[(U/I)^2 - R^2]^{1/2}$.

2.2.3 Measure the moment of inertia *J*

Measure the moment of inertia uses the slower method to determine losses by providing the use of a calibrated engine. The principle of this method is to record the speed engine retardation *N(t)* when cutting the drive motor. This helps determine the loss and the moment of inertia *J*. When suppresses the engine torque, the inertia of the rotating parts supplies each time the losses thanks to the following relationship:
$J\Omega d\Omega/dt + \Sigma Looses = 0$.
Knowing *J* and the $d\Omega/dt$ for the value Ω_n allows the calculation of $\Sigma Looses$ or conversely $\Sigma Looses$ knowledge and $d\Omega/dt$ allows calculation of *J*.

2.2.4 Regulator speed

Cruise control inverter is equipped with a control system that maintain constant speed regard less of the disruptions the system, this to some well-defined range [16]. It and in the same line idea, some types of control like the Arc cosine order was established [7] or [18]. A frequency converter is a system which allows to vary the speed of a motor in a wide range, but that does not guarantee the stability of this speed to a given value. In particular, this can vary with the external disturbances such as:

- Changes in the mechanical torque required by the driven machine;
- Variations in the mains voltage;
- Variations of the excitation current;
- The motor overheating.

The drive is open loop system as opposed to cruise control, which is a closed loop servo system. If one wishes to perform an automatic system capable of maintaining speed despite changes in expenses, you must:

- Measure the speed;
- Convert this speed in to another magnitude such that a potential difference;
- Compare this reference potential difference which represents the desired value of the speed;
- Amplifying the difference of these two voltages for driving the motor according to the block diagram below.

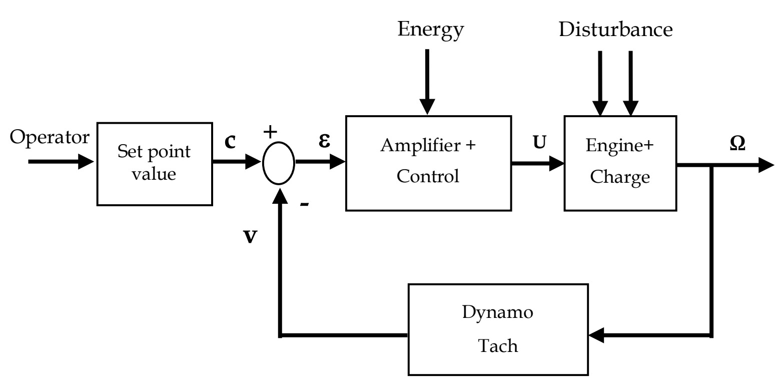

Figure 2: Block diagram of a speed controller.

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2.2.4.1 Function a speed regulator

Cruise control must not only reconcile the value of the primary variable is the speed with a reference value but still, it must fulfill a number of functions necessary to the good performance machines such as:
- The order specifies variables to avoid excessive speed in their development such as power control in a gradient induces necessary to obtain a good switching and consequently to maintain the collection in good condition.
- The transfer smoothly from one control mode to another. Thus, control of the speed control with current limiting must be done without brutality.
- The fit and easy optimization of a control loop independently of the other.
- The limitation of critical variables such as the current or the armature voltage [1] and [17].

2.2.4.2 Study theoretical behavior

This study aims to high light the temporal equations of DC motor with separate excitation during transient. Consider the following block diagram of a looped system and corrected where *R(p)* and *M (p)* represent the transfer functions of the correction and motor.

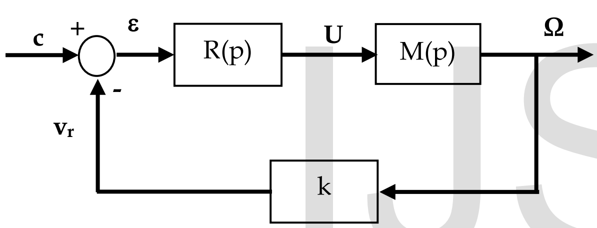

Figure 3: Block diagram of a looped system and corrected.

The electrical diagram of a separately excited DC motor is formed in its part induces an assumed active load, an inductance and a resistor respectively denoted *E*, *L* and *R*. For in against the part of the inductor, it consists of a series excitation inductance with the motor field strength noted by *l* and *r*, respectively. We can write that:

$u = Ri_2 + Ldi_2/dt + E$ $_{(1)}$ $E = k\Omega$ and $k = M_0 i_1$ $_{(1)}$.

The dynamics of the fundamental relationship to the motor gives us:

$\Gamma_m - \Gamma_r = Jd\Omega/dt$ $_{(3)}$ with Γ_m, Γ_r and J representing the engine torque, the load torque and the moment of inertia of the engine. While, $\Gamma_m = M_0 i_1 i_2 = ki_2$. The expression $_{(3)}$ then becomes:

$ki_2 - \Gamma_r = Jd\Omega/dt$ $_{(4)}$. Taking account of the expressions $_{(2), (3)}$ and $_{(4)}$ the expression $_{(1)}$ becomes: $u = k\Omega + RJ/k[d\Omega/dt] + LJ/k[d^2\Omega/dt^2]$ $_{(5)}$. By applying the Laplace transform to the expression $_{(5)}$, we obtain:

$\Omega(p)/U(p) = 1/k/[1 + 2\xi p/\omega_m + (p/\omega_m)^2] = M(p)$ $_{(6)}$ with $\xi = R/2L$ and $\omega_m = k^2/JL$. Equation $_{(6)}$ indicates that the transfer function M(p) of the engine has a denominator that is second order in p. Depending on the value of ξ, the second order system can be a periodic ($\xi>1$) or damped resonant ($0<\xi<1$).

2.2.4.3 Stability a system

To investigate the stability of a system it is important:
- In static, incorporate one or more integrations direct chain;
- In dynamics, to have a high gain for some pulsations.

Good stability of a system imposes the need to have a the lowest possible open loop gain in other words, low band width and the lowest phase, a minimum of integrators. The synthesis of a correction involves two distinct stages namely the definition of such correction by the correction phase advance, delay and calculation of parameters of the latter. Thus the most stability criteria used are those of the algebraic criterion of Routh-Hurwitz and Nyquist stability criterion or criteria revers. For meet the conditions of stability and of previous information, it is important to build by calculating a correction which should have the effect of giving ξ, ω_n and values of 0.7 and $2\xi/\varepsilon_1(\infty)$ where $\varepsilon_1(\infty)$ is the error in the unit ramp.

2.2.5 Current limitant

It is difficult to handle the torque using electronic components to ensure its control. Because the torque is equal to the current to a multiplicative factor, it is easy to manipulate the current in order to control this magnitude. Therefore, the current limiters are of particular importance. The principle of operation of the limiter is as follows:

- For a current I_m set by the limiter, the engine cannot absorb a higher current I_m;
- For a load imposing a current lower than I_m, the limiter works in linear mode;
- For a load applying a current greater than the motor I_m, the limiter operates in the saturation regime and limits the current in the motor I_m.

2.2.6 Expressions torque and speed

To determine the expression of torque and speed, considering I_d as the current supplied to the armature, there is a current $I_d/2a$ flowing in conductors when we *2a* voices parallel. The induction in the air gap be in gradual, tangential force by the average driver. $B_{moy}I_dL/2a$ where B_{moy} and *L* represent respectively the average induction under each pole and the length of the induit. For a conductor the armature of diameter *D*, the electromagnetic torque has the value $C = B_{moy}I_dLD/4a$ represents respectively the average induction under each pole and the length of the induit. For *n* conductors on the armature of diameter *D*, the electromagnetic torque has the value represent respectively the average induction under each pole and the length of the induit. For conductor the armature of diameter *D*, the electromagnetic torque has the value $\Phi = B_{moy}\pi DL/2p$ or, $B_{moy} = 2p\Phi/\pi DL$.

Referring B_{moy} in the expression of the torque, it becomes:

$C = pn\Phi I_d/2\pi a$.

For a given machine, the torque is proportional to field flux Φ and aware I_d absorbed by the armature. If the torque wants to reverse, reverse the current flow I_d or Φ. Electromagnetic current of the power absorbed by the armature by Id electromotive force against E can be expressed by the following relationship:

$EI_d = 2\pi\ CN = pnN\Phi I_d/a$ where *N* represents the rotation speed in rev /s. This suggests that $E = pnN\Phi/a$. However, the strength

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against electromotive equals the U_d alimentation armature voltage minus the voltage drop RI_d in resistor there of and the voltage drop e_B to the brushes contacts collectors. We have: $E = pnN\Phi/a = U_d(RI_d - e_B)$. We have an expression of speed: $N = a[U_d - (RI_d - e_B)/pn\Phi$.

The voltage drop $RI_d - e_B$ is low U_d before it can be concluded that the speed is proportional to the voltage and inversely proportional to flow. To reverse the speed, it will be reverse voltage or either the stream.

2.2.7 Alimentation under variable voltage U_d

Relationships $C = K\Phi I_d$ and $N = K'U_d/\Phi$ shows that in order to vary the speed, it is advantageous to act on the U_d voltage across the armature. When the motor is supplied at constant voltage U_d, the speed N can be increased by reducing the flux Φ flow. But, the more Φ flow, the lower the torque is low that the machine develops an *Id* current.

On the contrary, maintaining the Φ constant flows, one can develop the same torque at all speeds and thus the best use possible through the current of the armature and the inductor.

2.2.8 Non-reversible drives

When a DC motor must rotate in one direction and the drive does not require rapid braking, a speed controller reversible permitting the operation of the machine is used. Selection of a suitable rectifiers and order types generally depend on the power of the machine to be controlled [7], [18]. Thus: it should be noted that the composite bridge deteriorates less power factor when the rectified voltage decreases. By cons, it has the disadvantage of not being able to give only very low values for this voltage and to deliver rectified voltage of order three and not six. Therefore, it is desirable to put an inductor in series with the armature.

2.2.9 Reversible drives

The torque reversal in reversible drives is performed through the reversal of the field current or armature current. The member for performing inversion is an assembly of two rectifiers connected in anti-parallel or a triac.

2.2.10 Speed controllers for asynchronous motors

Speed regulators for DC motors, whose performance is excellent remain the most used. However, the collector prevents the DC machine some application fields like high speeds (above 3000 rev / min), high power supply voltage (more than 1500 V) and very strong power (more than 10 MW). The presence of collector requires monitoring and maintenance operation in less explosive atmospheres. This is one reason why one often uses the AC motors brushless synchronous or asynchronous. In order to vary the speed of rotation in asynchronous motors, use the following slip relationship: $N = (1-g)f/p$ with N, g, f and p respectively denoting the speed of rotation, sliding, frequency of the supply network and the number of pair poles. We can modify N by increasing the sliding or by changing the supply frequency [22]. In order to increase the slip of an engine running at constant frequency, may:

- Reduce the supply voltage, if the rotor cage;
- Increase the resistance per phase rotor by means of a rheostat, if the rotor is rings;
- Take more or less power between the rings.

By against the variation of the frequency f may require the construction of the voltages applied to the motor by taking properly selected portions of the mains voltages or the use of a rectifier circuit followed by a self-inverter.

4 Results and Discussion

In this part, it comes to comparing the measurements of two quantities to transient and permanent regimes. This is the speed set point as input variable and the voltage supplied by the tachymetry speed image output variable.

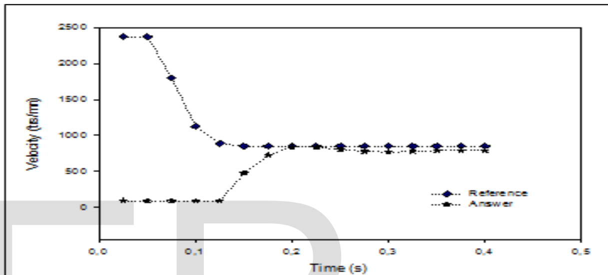

Figure 4: Behaviour bondage at 500 trs/mn

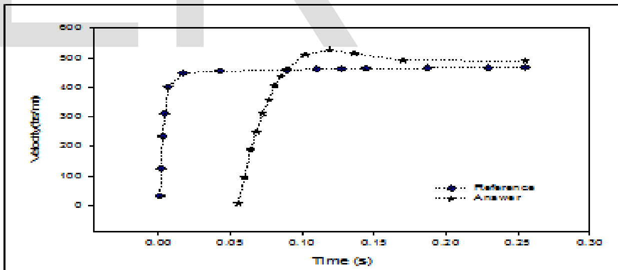

Figure 5: Behaviour bondage at 1000 trs/mn

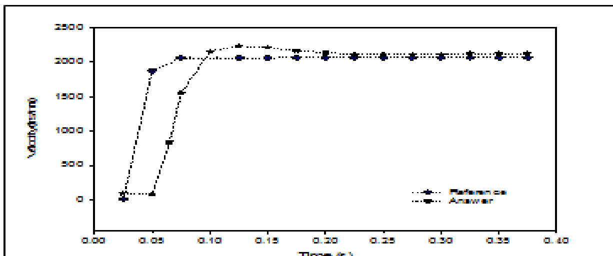

Figure 6: Behaviour bondage at 1500 trs/mn

Given the curves of figures 4 and 5 are deduced exceeding the values D and damping coefficient ξ. Using the following relation:

$$D=\frac{\theta_m-\theta_0}{\theta_0} \text{ (en \%)}$$

The calculation gives D =8.5%

The damping coefficient is related to the overrun due to the following expression:

$$D = \exp\left(-\frac{\pi\xi}{\sqrt{1-\xi^2}}\right)$$

Knowing the exact value of the excess D, we deduce that the amortization □=0.6.

The pace of curves allows us to say that our system is second order and its transfer function can be written as:

$$H(p) = \frac{k}{1+2\frac{\xi}{\omega_0}p+\left(\frac{p}{\omega_0}\right)^2}$$ where k and □0 respectivelydenotes a constant and the cut-off frequency. The pseudo period is related to the cut-off frequency and the damping coefficient by the equation below:

$$Ta = \frac{2\pi}{\omega_0\sqrt{1-\xi^2}}$$

Thanks to the pulsation values cut and damping coefficient calculated previously, we deduce the following transfer function:

$$H(p) = \frac{k}{1+0{,}2p+0{,}03p^2}$$

This transfer function corresponds to that of a second order system with a value of damping coefficient less than 0.7.

We can say that the system is stable. The graph above, we deduce that the steady state error of the system is 0.1. One can conclude that the system is accurate. Performing the same calculation in figure 6 shows an overshoot of 3.8% and therefore a damping coefficient of about 0.7. In this case; one is in the presence a critical system. From these graphs, it can be said that when the speed increases, the stability of the system decreases. The N max speed of 1500 rev / min maximum speed is considered not to cross otherwise damage the engine. We note that at its rated speed, when the engine is subjected to various loads, leaving only the smaller load to large load available, the current stabilizes at 8 A regardless of the increased load and that the speed is equal to the set point. In view of the above, we can conclude that the controller controls the torque.

The main experimental results above measured quantities can be obtained like the speed according to the instructions, the current induced according to the instructions, of the armature voltage as a function of the set point, the speed depending on the armature voltage and measurement according to the speed.

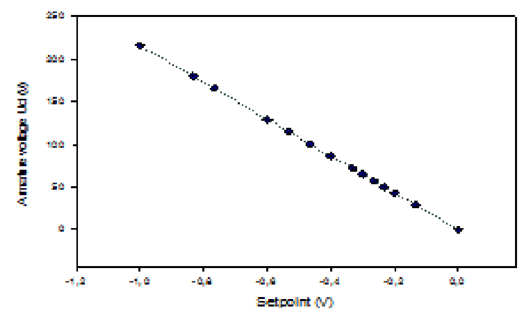

Figure 7: Armature voltage as a fonction of setpoint.

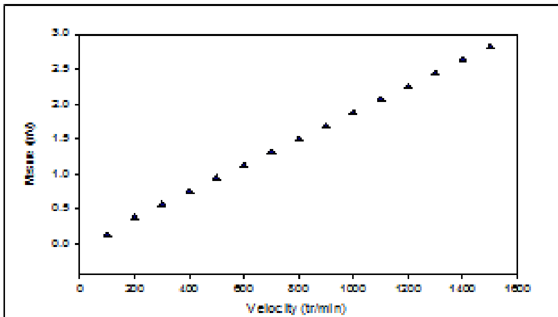

Figure 8: Curve of the measurement depending on the speed.

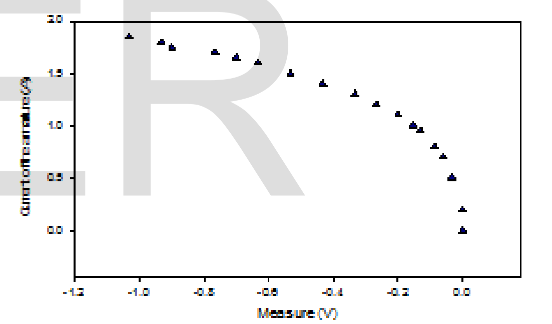

Figure 9: Current curve of the armature as a function of the setpoint.

The different results such as those relating to the operation, the operation or performance actually translate the desired qualities. The disadvantage that controller is the lack of precision in the speed potentiometer.

4 Conclusion

The study on the speed control of a DC machine with separate excitation torque control was mainly to implement a speed controller for speed control when stopped, the possibility of enslavement The soft start, removing surges, torque control, the ability to withstand overloads and protection against short circuits. Different presets have been made to the controller supplied with single-phase. This controller operates at constant power. Indeed, for the rated speed, it is necessary after the motor voltage and the available network to reduce the nominal field current of machine. Different results such as those relating to the operation, exploitation or performance, actually translate the desired qualities. By cons, this controller has the main disadvantage the lack of precision in the speed potentiometer. For this purpose, a digital controller or microprocessor u insertion improve the accuracy of operation.

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