A Study on the Improvement of the Mechanic Eccentric Power Presser Dynamics by using Variable Frequency Induction Motor Drives

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Abstract: - This paper proposes the improvement of eccentric power presser dynamic by using variable speed induction motor drives. For this study, the power presser and the motor control schemes have been modeled and simulated using the Matlab – Simulink software. Two control schemes are investigated: Volt-Hertz and Direct Torque Control. A brief on the operation principle and the Simulink models of each control scheme is presented. The comparative graphical results can illustrate their effect on the power presser dynamics.

Key-Words: - Power Presser, Induction Motor, Volt/Hz Control, Direct Torque Control

1 Introduction

It is known that mechanic eccentric pressers are driven by three-phase induction motors working at invariable speed. A part of the kinetic energy accumulated by the flywheel is yielded in the plastic deformation process during the active portion of the work cycle. In the following no load portion the motor tends to restore the no load speed.

If the processing is commanded manually (the process control is executed by operator), the no load period is large enough for the flywheel to reach the nominal speed. On the other hand, if the process is performed in automatic mode (one hit per flywheel rotation) and the deformation process requires a large quantity of energy, the no load period of the cycle may become insufficient to recover the loss of energy. This inconvenient can be overcome by using a variable speed drive.

The induction motor will be supplied by a Voltage Source Inverter. The VSI and the control schemes presented below, allow modifying the motor speed. Due to these control schemes it is possible to utilize the same presser for various operations at proper process speed (cupping, punching etc.). In addition, increasing the number of cycles per time unit (if the nature of the process allows this) can meliorate the process productivity. This advantage is determinant for a small or medium – sized company for which it is difficult to have a large number of different size and type pressers.

2 The dinamic model of the eccentric power presser

This power presser is of non-geared type. It has a flywheel which rotates directly the main shaft and which is driven by the electric motor using a belt transmission.

The large values of deformation force, which varies during the processing cycle, explain the presence of the flywheel. The flywheel has an important contribution to the deformation energy and it maintains the uniformity of the movement, leading to the reduction of the dynamic loading – which otherwise could affect the working piece. A part of the kinetic energy stored by the flywheel is absorbed by the deformation process in the active portion of the work cycle. In the remaining portion the motor tends to re-establish the operating speed for the next cycle.

The power presser model is based on the calculus of the crank turning moment M_t produced by the deformation force at the presser shaft, as shown in equation (1) [6]:

$$M_t = F_d \cdot R \cdot \left(\sin\alpha + \cos\alpha \frac{R}{L} \cdot \frac{\sin\alpha}{\sqrt{1-\left(\frac{R}{L}\right)^2 \sin^2\alpha}} \right) \quad (1)$$

where:
F_d is the deformation force, on the direction of translation;
α is the flywheel current angle:
$\alpha = 0^o$, at the upper position of the ram;
$\alpha = 180^o$ at the lower position.
R is the crank radius;
L is the length of the connecting-rod.

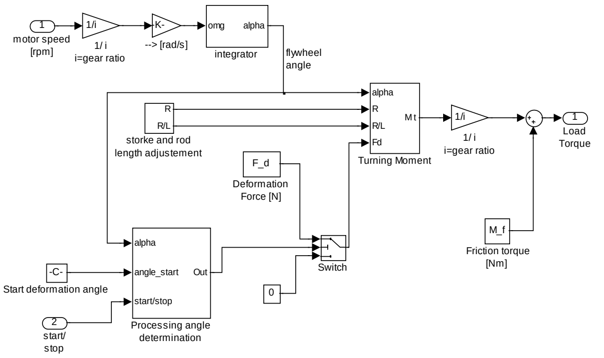

Fig. 1. The dynamic model of the power presser

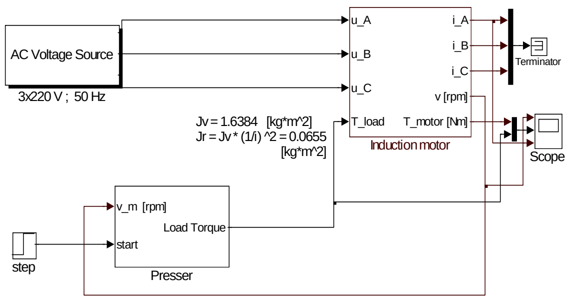

Fig. 2. The model of the system comprising the power supply, the power presser and the induction motor

The flywheel current angle is obtained by integration of the shaft angular speed.
The deformation force (F_d in the Simulink model) is applied between the processing angle and 180 deg. (which corresponds to lowest movement point).
Finally, the torsion moment reflected to the motor axis is calculated considering the gear ratio.
The load moment at the motor shaft is calculated by dividing the torsion moment M_t by the gear-ratio "i":

$$M_r = \frac{M_t}{i} \qquad i = \frac{\Omega_{motor}}{\Omega_{flywheel}}$$

The effective moment of inertia at the motor shaft is given by the expression:

$$J_e = J_m + \left(\frac{\Omega_{motor}}{\Omega_{flywheel}} \right)^2 J_v$$

where:
J_m is the moment of inertia of motor
J_v is the moment of inertia of the flywheel, obtained from instruction book.
J_e is one of the parameters of the induction motor model.

3 Models of the variable frequency control schemes

The requirements of the controlled electric drive are both the possibility of an adjustable work speed, and the ability to apply a certain speed profile along the duty cycle. Therefore it is necessary to use a control scheme which can provide a fast torque response and the availability of the peak torque even at low speed.
Two control schemes were investigated: the widely used Volt-Hertz control – which is simple, robust and cost-effective, and a high dynamic performance control scheme - Direct Torque Control (DTC). These schemes are briefly presented below.
The purpose of the Volt-Hertz control scheme is to maintain the air-gap flux of AC induction motor constant in order to achieve higher run-time efficiency.
The speed variation is obtained by controlling the stator voltage and the stator voltage frequency. Stator voltage is required to be proportional to frequency in order to maintain a constant flux, $\psi_s = U_s / \omega_s$. The Simulink model of the open loop Volt-Hertz control of the drive is presented in figure 3.
An improved Volt-Hertz control is the Closed Loop speed control by slip regulation, as seen in figure 4. In this control scheme, the measured rotor speed is compared with the reference speed and an error signal is generated. Based on the speed error, a PI controller generates the slip frequency, which is then added to the rotor frequency to obtain the reference stator voltage frequency. The amplitude of the reference voltage is calculated in the same way as in Open Loop Volt-Hertz. Finally, this reference voltage is applied to the voltage inverter using Pulse Width Modulation (PWM).

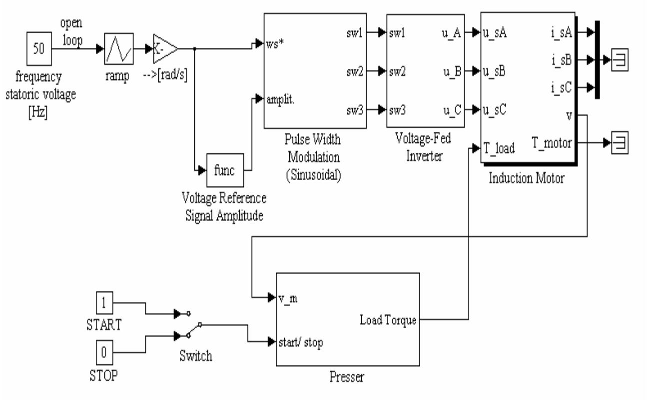

Fig. 3. Open Loop Volt/Hertz Control

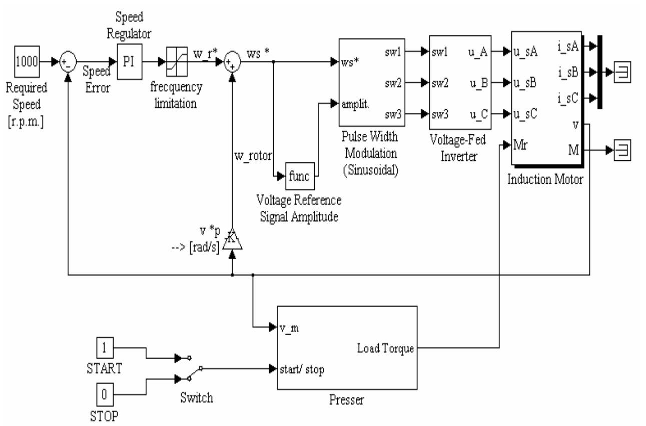

Fig. 4. Closed Loop Volt/Hertz Control

The second control method presented is the Direct Torque and Flux Control (DTC). The basic idea of DTC is to choose the best voltage vector in order to control both stator flux and electromagnetic torque of machine simultaneously. In the control model, shown in figure 5, the actual flux and torque magnitudes are estimated using the machine terminal voltages and currents. The reference values of the flux and torque magnitudes are compared to their corresponding estimated values using hysteresis comparators [3]. Depending on the outputs of these comparators and the position of the flux space-phasor, the proper inverter voltage space-phasor is selected, from a switching table.

DTC is characterized by a very fast torque response and a relatively simple control scheme. Comparing to the other high performance scheme – the vectorial control – DTC has some advantages: the control scheme is simpler, it does not need voltage decoupling circuits or coordinate transformations, and it is easier to implement a sensorless control.

The most important disadvantage of DTC, the high torque ripple, does not affect the performance of the drive, due to the large flywheel moment of inertia.

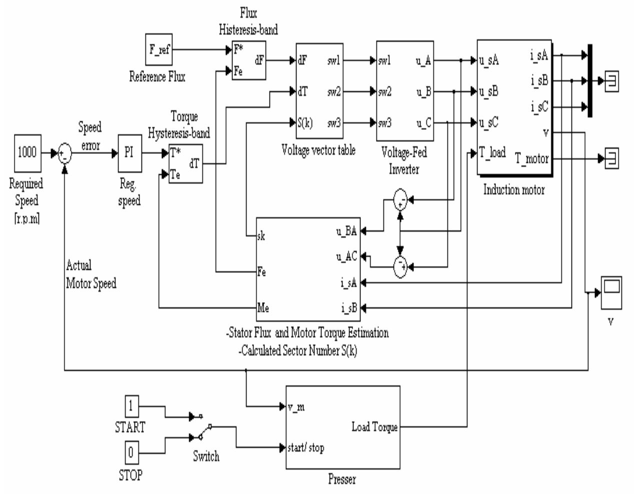

Fig. 5. Direct Torque Control

3 Results

For the modeling it was used an power eccentric presser PAI 6.3, driven by an induction motor.

In the model, the following presser working parameters are specified:

- deformation force Fd (the maximum allowed value is Fd_{max}=6.3 tf);
- deformation angle, which is the flywheel angle corresponding to the beginning of the deformation;
- ram course

The induction motor parameters are:

$P_n = 993.6$ W ; P = 2 pole pairs; $R_1 = 7.13\ \Omega$; $R_2 = 8.18\ \Omega$; $L_m = 0.604$ H; $L_1 = L_2 = 0.0301$ H ; $\omega_n = 1420$ r.p.m. = 148.6 rad/s ; $T_n = 6.7$ Nm

Rotor moment of inertia: $J = 0.006\ \text{kg}\cdot\text{m}^2$

Presser shaft inertia moment reflected to the motor axis is: $J_e = 0.0655\ \text{kg}\cdot\text{m}^2$

In the following subsections there are presented the numerical results of the simulated operating of the eccentric power presser using the considered motor control schemes.

3.1 Open Loop Volt/Hertz Control

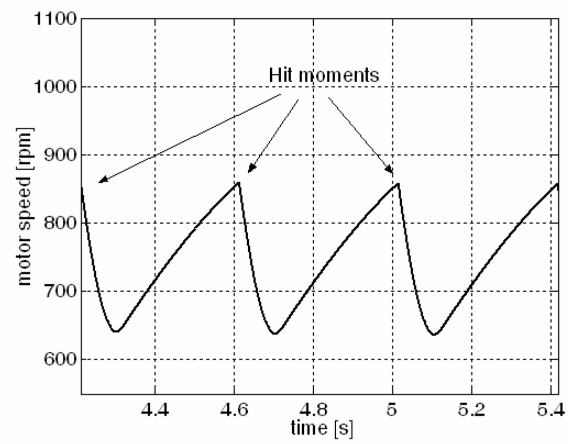

Fig. 6. Speed variation

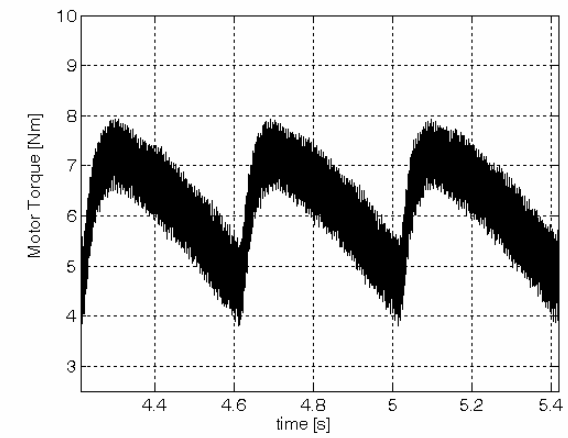

Fig. 7. Motor torque variation

3.2 Closed Loop Volt/Hertz Control

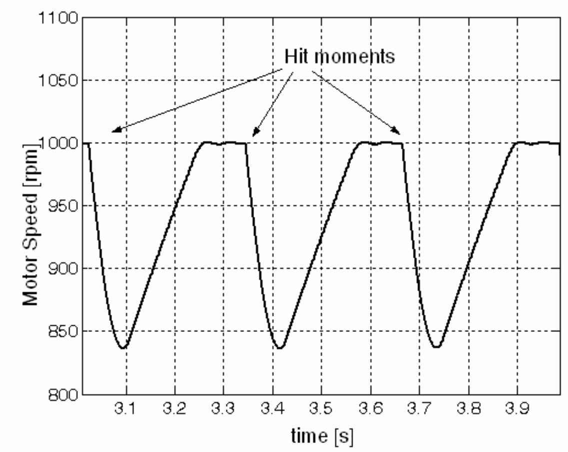

Fig. 8. Speed variation

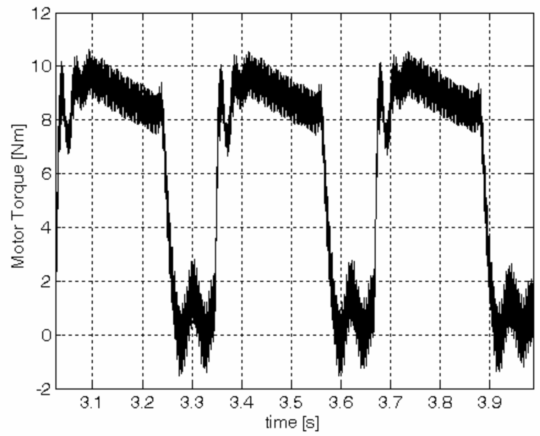

Fig. 9. Motor torque variation

3.3 Direct Torque Control

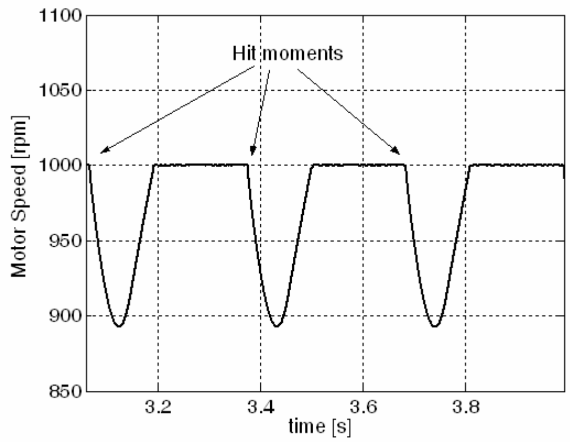

Fig. 10. Speed variation

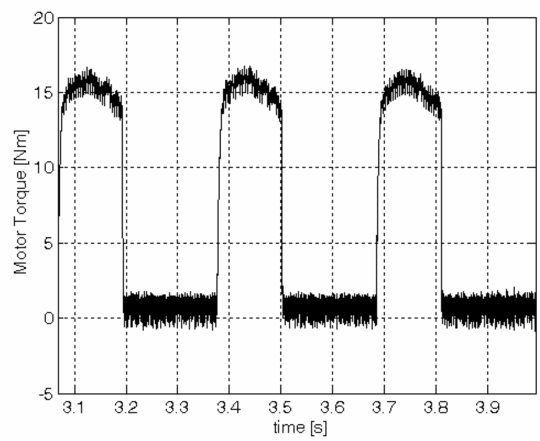

Fig. 11. Motor torque variation

Comparing the three situations presented above, it can be noticed that the DTC offers the fastest speed recovery after the deformation phase in a working cycle.

If the load torque raises, the motor deceleration in the deformation phase and the kinetic energy loss become more significant, therefore the average speed of the flywheel decreases. A limit situation can occur at high load, when the average speed decreases from cycle to cycle, leading to the presser blocking. Such a situation is illustrated in figure 12, for the closed loop Volt-Hetz control.

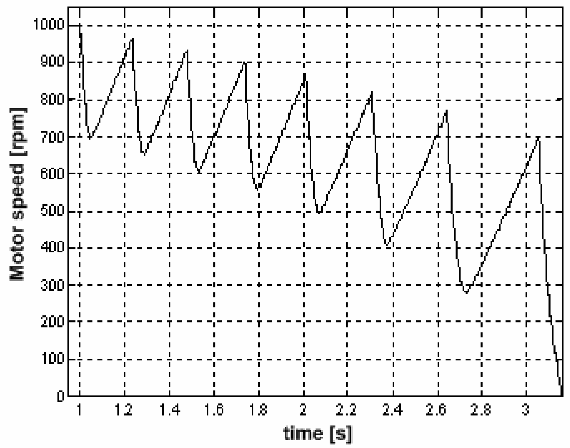

Fig. 12. Motor speed with Volt-Hertz control, at critical high load

The same load torque was applied to the presser when the motor is controlled using DTC. Due to the dynamic performance of this control, the average speed is maintained constant and the presser blocking is avoided, as seen in figure 13.

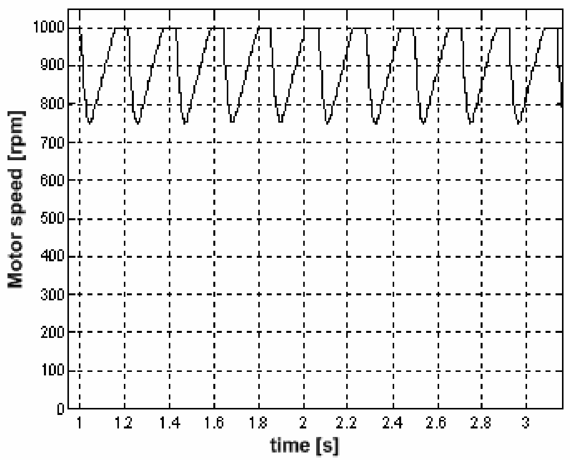

Fig. 13. Motor speed with DTC control, at high load

4 Conclusion

The use of the variable speed control of the induction motor drive has the following advantages: the same power presser can be utilised for performing different operations, at process specific speed; the productivity can be increased by rising the number of cycles per time unit; the efficiency of the power presser can be controlled and improved.

Two motor control methods were investigated for this application. The Volt-Hertz control scheme has the advantage of simplicity and cost effectiveness. However, it was shown that the power presser operating load range is limited, because this control scheme has a poor dynamic performance. The Direct Torque Control, due to its fast torque response, can be considered suitable for high dynamic requirements of the power eccentric presser.

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