Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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Annals of DAAAM International

A SOLUTION OF IMPROVING EFFICIENCY OF THE MECHANICAL PUNCH PRESSES EQUIPPED WITH TORQUE-CONTROLLING VARIABLE SPEED DRIVES

PATURCA, S[anda] V[ictorinne]; COVRIG, M[ircea]; GHEORGHE, S[tefan] & VELICU, S[tefan]

Abstract: *This paper presents a solution of improving the efficiency of the punch presses equipped with variable speed drives, in case of working in continuous mode (automatically fed with material). The solution consists in uniform motor torque spreading along a working cycle, so that the no-load portion, when motor has the worst efficiency, is eliminated. The effectiveness of this method was tested by numerical simulation, using a press model which was built and experimentally validated by the authors. There are presented numerical and graphical results showing the new behaviour of the motor and the amount of efficiency gained in different operating situations.*
Key words: *punch press, efficiency, variable speed drive*

1. INTRODUCTION

The mechanical punch presses are widely utilized in small and medium size industrial units, due to their simplicity, reliability and low cost. They are used in various operations, such as punching, cupping, stamping, bending, shearing.

Their working principle is based on the rod-crank mechanism. The presser shaft is attached to a flywheel which is driven by a three-phase induction motor. The motor is usually directly connected, but in present the number of presses equipped with variable speed drives (VSD) is increasing.

Besides their purpose of varying the motor speed, the VSD's have proven its advantages regarding the energy cost savings in many applications (centrifugal pumps, conveyors), as mentioned in literature [Burnes, 2003], [***, 2000].

However, the authors have not found any reference related to the efficiency in case of mechanical presses equipped with VSD's. Consequently, the authors analyzed the efficiency of these machine tools and also proposed a solution for improving it, and the results are presented in this paper.

The solution is applicable, in the presented form, in case of motor control strategies characterised by linear torque response with respect to command quantity: vector control or Direct Torque Control (DTC) [Takahashi & Noguchi, 1986]. Due to the advantages of DTC related to this kind of application [Paturca et al., 2007] and the previous studies made by the authors in applying DTC for improving presses dynamics [Paturca et al., 2008], it was chosen DTC as the motor control strategy.

The efficiency analysis was performed by numerical simulation, for different operations and loads of the press. There are briefly presented the press model, the DTC features, the solution proposed for efficiency improvement and the obtained results.

2. THE PRESS MODEL AND THE VSD SCHEME

The presser model was built by considering the dynamics of the motor-presser system, which is expressed by the equation 1,

$$M - M_l = J\frac{d\Omega}{dt} \tag{1}$$

where: M is the motor electromagnetic torque, M_l is the load torque at the motor shaft, J is total inertia, and Ω is the angular speed of the rotor. The load torque is calculated using turning moment at the press main shaft [Paturca et al., 2008].

Equation (1) is used in the motor model to obtain the rotor angular speed Ω, having the load torque calculated in the presser model. On the other hand, the presser model uses Ω to obtain by integration the current presser shaft angle α, which is used to determine the load torque. This interdependency between the two models was resolved by calculating the angular speed in a circulatory manner, starting from an initial known value of the load torque. The press model was experimentally validated by the authors [Paturca et al., 2008].

As stated in the introduction, it was used DTC as the motor control strategy. The basic idea of DTC is to choose the best inverter switching pattern in order to control both stator flux and electromagnetic torque of machine simultaneously [Takahashi, 1989]. It is characterized by a very fast torque response and a relatively simple control scheme.

The scheme of the press drive is presented in figure 1. The DTC algorithm receives the torque reference from a speed controller. The torque reference calculator block, between the speed controller and DTC, is used only to adjust the torque reference according to the solution proposed for efficiency improvement, which will be explained in the next paragraph.

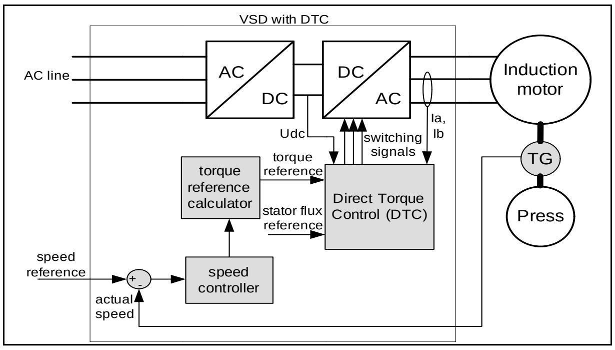

Fig. 1. Basic scheme of the press drive

3. THE PROPOSED SOLUTION FOR PRESS EFFICIENCY IMPROVEMENT AND THE RESULTS

The solution consists in uniformly spreading the motor torque over a working cycle, so that the no-load portion, when motor has the worst efficiency, is substantially reduced.

The solution is applicable when the press is working continuously, performing an operation every cycle. It is implemented in the control scheme by means of the torque reference calculator, illustrated in figure 1.

In an initial phase, for a few cycles, the torque reference is provided directly by the speed controller. In the same time, it is calculated the average torque per cycle, using equation 2,

$$\tilde{M} = \frac{1}{T_{cycle}} \int_{0}^{T_{cycle}} M(t)dt \qquad (2)$$

where T_{cycle} is the cycle period.

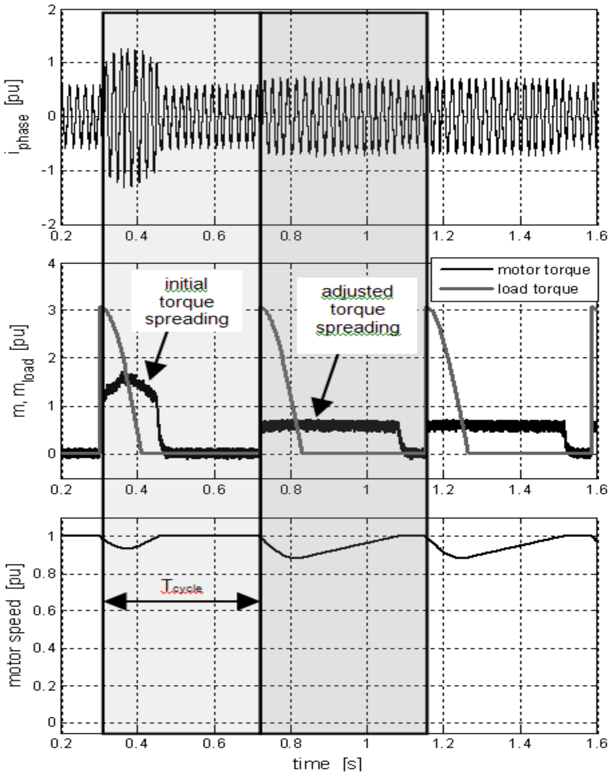

Fig. 2. The press drive behavior before and after the torque adjustment: motor phase current (top), motor and load torque (middle) and motor speed (bottom)

After the initial phase, the torque reference provided by the speed controller is limited at the previously calculated average torque, which is increased by 10%, in order to take into account that the real load torque is not exactly the same from one cycle to another.

In order to illustrate the behavior of the press drive, there are represented in figure 2 the evolution in time of one phase current, motor and load torque and the motor speed, before and after the torque spread adjustment according to the proposed solution. The results were obtained from the simulation of a cupping process. The quantities are expressed per unit, taking the corresponding rated values as the base values.

It can be observed that when the torque adjustment and correspondingly the new torque spreading are applied, the motor still reaches the no-load speed before the next stroke occurs, and the no-load duration is decreased. In the same time, as expected, the current overshoot is much lower than in the case when no torque adjustment was applied. In order to reveal the effectiveness of the proposed efficiency improvement solution, there were conducted numerical simulations of the press performance in case of directly connected motor and DTC drive controlled motor, with and without torque adjustment. Some results, obtained for a continuous cupping process, are comparatively presented in figure 3, where the press efficiency is represented as function of the press loading (expressed by the deformation force). The deformation force is expressed per unit, taking the maximum press force as the base quantity.

The press efficiency was defined as in equation 3,

$$\eta = \frac{L}{W} \qquad (3)$$

where L is the mechanical work in a press cycle and W is the energy absorbed by the motor in a press cycle.

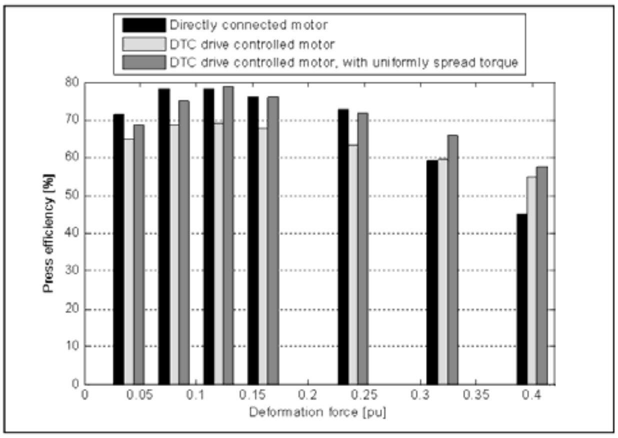

Fig. 3. Press efficiency versus deformation force, showing the effectiveness of the proposed solution

In the case of drive controlled motor, the efficiency was multiplied by 0.92, which is a usual value of drive efficiency.

The graph in figure 3 shows that the DTC drive provided a better press efficiency than the directly connected motor at heavy loads (32% of maximum force), when the slip losses of the uncontrolled motor become significant. When DTC drive with the proposed solution was used, the efficiency improvement started at much lighter loads (12% of maximum force).

4. CONCLUSION

This paper presented a proposed solution of improving the efficiency of the mechanic presses equipped with variable speed drives. The solution was tested by numerical simulations, using a press dynamic model which was created and experimentally validated by the authors. The results showed that the solution can offer a better press efficiency for a wide load range, comparing to the efficiency obtained by using directly connected motor and drive controlled motor.

The solution, in the actual form, is only applicable for variable speed drives that use vector control or Direct Torque Control. As further work, the authors intend to extend the solution applicability to the Volt-Hertz control, which is the most widely used motor control type in industry.

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