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Energy-Efficient Drive Concepts in Metal-Forming Production

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Abstract

Nowadays, efficient drive solutions for the production industry are more important than ever. In view of this, new energy-efficient drive concepts for forming presses and sheet metal feeding systems are developed at the IFUM. The novel press drive is based on a power-split design, which allows a variable ram-kinematics with reduced total costs of ownership in comparison to conventional servo presses. The new feeding concept will be able to realize the contactless feed of electrically conductive sheet metals by means of electromagnetic forces. Since only the sheet metal has to be accelerated, the energy efficiency and feeding rate can be increased significantly.

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Keywords: metal forming; servo press; sheet metal feeder; energy efficiency.

1. Introduction

The current technology for the production of sheet metal parts in high quantities is primarily based on the use of mechanical forming presses [1]. A common design is the eccentric drive in addition to a flywheel which is driven by an asynchronous electric motor. The flywheel is coupled with the eccentric shaft via a clutch and the ram is mechanically connected to the eccentric shaft by means of conrods. The eccentric bearing of the conrods leads to a sinusoidal motion of the ram (Fig. 1).

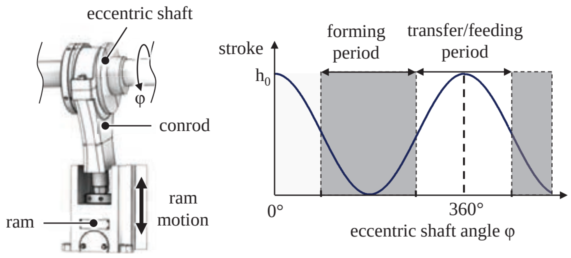

Fig. 1. Structure of mechanical eccentric presses and the respective ram kinematics

The ram's stroke rate is regulated by the rotational motor speed with a frequency converter. In order to realize a high output rate automated press lines are used, in which the sheet metal is fed from a coil by means of sheet metal feeders.

1.1. Servo Presses

Due to global market dynamics, decreasing product prices and the increasing range of product variants, the metalworking industry is forced to realign its production lines. These challenges are currently managed by means of the flexibility of servo presses [2].

The major advantage of this drive technology is that the ram velocity can be set flexibly with regard to the specific requirements of each forming process and the production output. On the one hand the ram can be accelerated in the non-productive area of the ram movement. Thus, a higher productivity of the production line is attainable.

On the other hand additional operations (e.g. bonding, cutting etc.) can be realized in one stroke by means of controlled ram deceleration [3]. The profit is a simplification of the entire production chain.

Typical for servo-driven presses is the drive system consisting of one or more slowly rotating servo motors with high torque capability. The connection to the crank shaft is either direct or by means of a gear stage. To provide high

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dynamics, the press drive is designed with the lowest possible rotary inertia. That is the reason for the absence of the mechanically coupled flywheels which are normally used for energy storage in mechanical presses. Thus, the forming energy which is influenced by the force peaks of the forming process has to be provided completely by servo-motors in a short time range [4]. Several disadvantages are the consequence. The servo-motors and the power electronics have to be dimensioned corresponding to these force peaks. Furthermore, the temporarily occurring force peaks lead to an unbalanced power consumption of the press. The compensation of this effect is done nowadays by means of:

- mechanical energy storage by an electrically coupled flywheel
- electrical energy storage by capacitors

These energy storage systems enable energy recovery as well as a reduction of AC power peaks, but lead to higher total cost of ownership.

1.2. Sheet Metal Feeder

With the development of advanced servo-motor-driven presses the non-productive time between two forming processes can be reduced significantly in many cases. However, this leads to higher requirements for the performance of the periphery of presses, especially of the installed sheet metal feeding system. Today mechanical grip and roll feeders are used [5], shown in Fig. 2. In both concepts the sheet metal positioning is realized by the transmission of frictional force to the sheet.

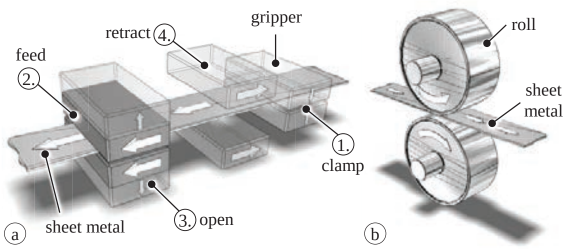

Fig. 2. Concepts of mechanical feeders: (a) grip feeder; (b) roll feeder

In many cases roll feeders are preferred due to their high performance in comparison to grip feeders. Today, the most common drive variant is also the servo-driven roll feeder [6], of which various variants exist. Usually, the connection from the motor to the roll's drive shaft is realized by a gearbox. In special applications both rolls are even separately driven by two servo motors, which are synchronized electronically. Due to the high quantity of components, most of the input energy is used for their acceleration. The acceleration capability of mechanical feeders is limited and thus also the feeding rates. Furthermore, the energy balance is reduced.

Another major problem is the mechanical contact and the high pressure in the area between the sheet and the feeder's rolls or grippers. In many cases the mechanical contact leads to a damaged sheet surface or even to plastic deformation [7, 8], especially when feeding sensitive materials, to abrasive wear of the feeder's components and also to slippage, resulting in position errors.

Limited feeding forces and high contact pressures are major challenges which often restrict the output rate of the press.

2. Power-Split Drive Concept for Servo Presses

To reduce the acquisition and operating costs and simultaneously use the advantages of a servo press, a completely new drive concept would be required. At the IFUM an innovative drive concept for eccentric presses was developed. A programmable ram kinematics combined with rather low acquisition costs compared to current servo presses are the main objectives.

The basis of this power-split press drive system is a power-split gearbox (Fig. 3). Its task is to summarize the mechanical power of the primary and the secondary drive and direct it to the eccentric shaft of the press. A flywheel which is mechanically coupled with the primary drive is used for energy storage. The specific amount of energy needed for the forming operation is taken jointly from the flywheel and the secondary drive. Arising electrical power peaks of the secondary drive can be balanced by the primary drive by a regenerative breaking of the flywheel. In case of a regenerative breaking of the secondary drive, the excess energy can be supplied to the flywheel by means of the primary drive motor. There is no need for costly storage capacitors or flywheels. A significant reduction of acquisition costs can be expected.

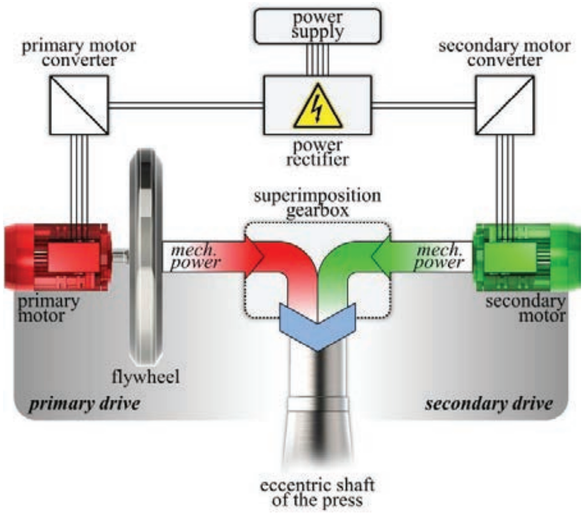

Fig. 3. Functional layout of the power-split press drive

The economic advantage of this drive concept, compared with conventional servo-electrically driven presses, is that just a fraction of the electrical energy has to be delivered directly by one of the drive motors. Losses resulting from energy transformation and storage processes are reduced.

For a better understanding of the functionality, a snapshot of the electrical and mechanical power flow is shown in Fig. 4.

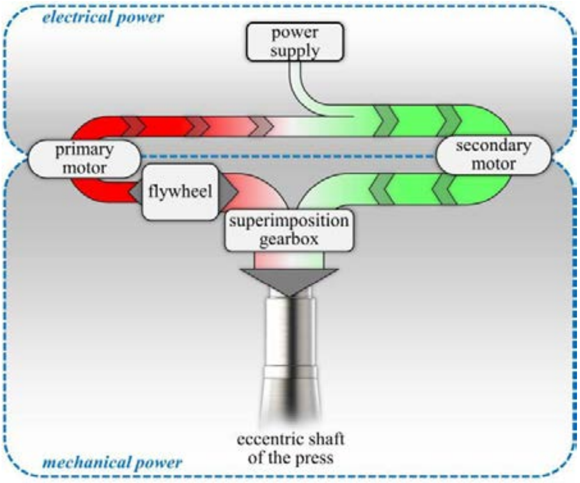

Fig. 4. Power flow chart at high press force

The mechanical power, which must be applied to the forming operation, has to be provided proportionally by the flywheel and the secondary motor. The main part of the electrical power for the secondary motor will be provided by generative breaking of the flywheel by the primary motor. In combination with the constant power supply, peaks of the secondary motor will be covered in this way. The electrical load of the power grid remains constant during the entire stroke.

The energy savings primarily depend on the adjusted ram kinematics. To illustrate the potential energy savings with the power-split press drive, the percentage distribution of the required power for a simulated deep drawing process is shown in Fig. 5.

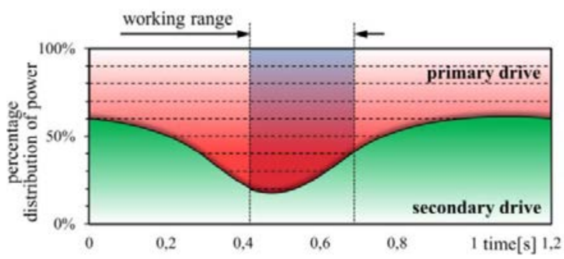

Fig. 5. Percentage distribution of power

The secondary drive (dynamic servo motor) only contributes a small portion of the total power required in the working range. In this range, only a small percentage of the required power must be taken from the energy storage. With a conventional servo press the percentage is close to 100 % and thus significantly higher. Energy losses resulting from energy conversion and storage processes of conventional servo presses can be reduced by up to 80% (Fig. 6).

Several multibody simulations confirmed the functionality of this drive concept [9] and were the basis for the design/construction of a demonstrator press.

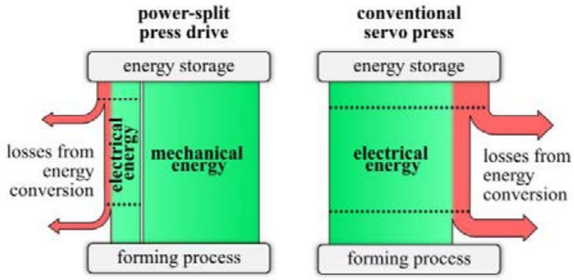

Fig. 6. Electrical energy losses of the power-split press drive and a conventional servo press

2.1. Refit of a conventional eccentric press

To validate the functionality of the power-split press drive and the corresponding control concept, a C-frame eccentric press (Weingarten XTR I) will be equipped with modern drive components (Fig. 7).

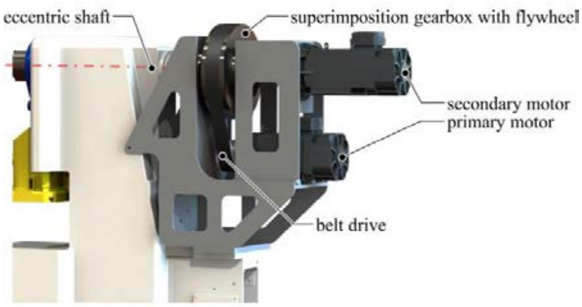

Fig. 7. Construction of the refit C-frame eccentric press (Weingarten XTR I)

The main requirements for the technical sizing process were a realizable press force of 500 kN at 30° before the bottom dead center, a nearly constant power input and a stroke rate of 50-60 1/min. The electrical hardware for the power-split press drive is shown in Fig. 8.

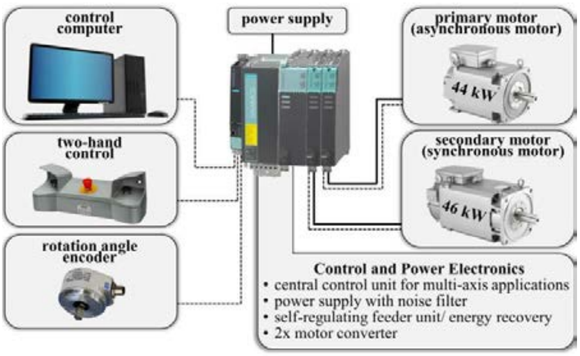

Fig. 8. Electrical hardware of the power-split press drive

All electrical components are commercially available. Both drive motors as well as the motor converters are overdimensioned by a factor of 1.3, to ensure a sufficient buffer to the performance limit of the motors during the parameterizing process and the testing phase. A specially developed control concept to realize a process-adapted ram kinematics with constant power consumption from the electric grid was integrated in the central control [10].

The superimposition gearbox is manufactured individually for the power-split press drive. The required flywheel, the planetary gear, the reduction gearings and the clutch-break combination are integrated in one housing to achieve a compact design. The planetary gear, which sums up the power of the two drive trains, is the most important component of this press drive. The secondary motor is directly coupled to the sun gear and the flywheel directly to the inertial gear. Both drives are permanently connected via the planetary gear. Switching between both drives, known from other drive concepts, is not necessary. In Fig. 9 the schematic coupling of the planetary gear as well as the main facts about the superimposition gearbox are shown.

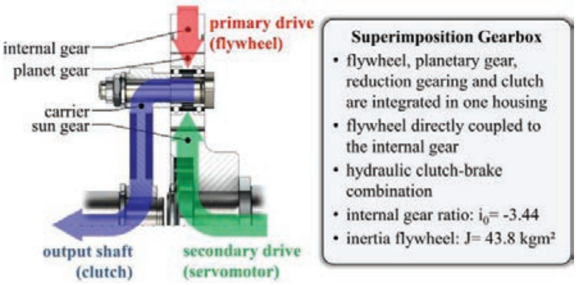

Fig. 9. Schematic coupling of the planetary gear and facts about the superimposition gearbox

The carrier is the power output of the planetary gear and directly connected to the clutch-brake combination. A reduction gear stage at the output of the superimposed gearbox reduces the rotational speed of the eccentric shaft and the torque at the gearbox components.

Various practical tests with this developed design should confirm the basic operation, validate the simulation results and demonstrate the economic potential of the new drive concept compared to usual servo presses.

3. Electromagnetic Sheet Metal Feeder

Furthermore, an efficient drive system was developed for a peripheral press component: the sheet metal feeder. In order to increase the performance of today's available mechanical grip and roll feeders, an electromagnetic feeding system was developed at the IFUM [11]. The new principle is based on the asynchronous linear motor, where the electrically conductive sheet metal is used directly as the moving secondary part. The structure of this feeder is shown in Fig. 10.

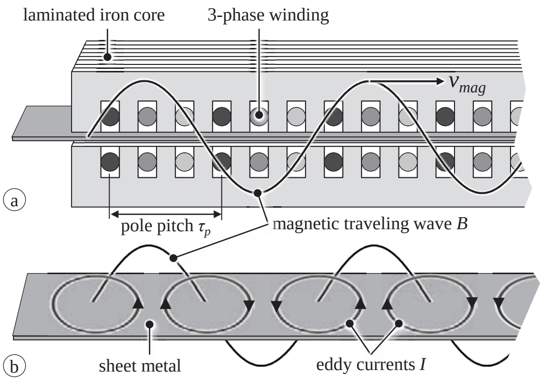

Fig. 10. Functional principle of the electromagnetic feeder

The feeder comprises two identical stators with an integrated three-phase winding. The stators are arranged oppositely. The sheet metal is located inside the air gap between the stators. This double stator arrangement is used in order to prevent the formation of attraction forces on the sheet. The stators generate a traveling magnetic field in the air gap. In case of a relative velocity of the sheet, eddy currents are induced inside the electrically conductive sheet metal. Due to the interaction between the currents I and the magnetic field B, a translational force F_L is applied to the sheet in accordance with the Lorentz-law [12]:

$$F_L = (B \times I) \cdot w_S \tag{1}$$

wherein w_s is the sheet width. Using a frequency converter the magnetic field's magnitude and velocity v_{mag} (Eq. 2) can be controlled via the phase current frequency f and thus the feeding force and the position of the sheet metal [13].

$$v_{mag} = 2 \cdot f \cdot \tau_p \ , \tag{2}$$

with τ_p as the pole pitch (Fig. 10). The new feeding method offers two main advantages. First, the accelerated mass is significantly lower than in conventional roll feeders due to the lack of rolls. Only the sheet metal has to be accelerated. In this context, an increase in energy efficiency is expected compared to conventional systems.

Secondly, the forces are initiated completely without contact so that no damage can be caused the sheet surface.

3.1. Simulation

In order to investigate the new feeding principle, especially the attainable forces, a 3D finite element model was built (Fig. 11). Nonlinear magnetic properties for the stators and the sheet metal were implemented to consider saturation effects of the material. The numerical model was used to optimize the feeder design, including the distribution of the stator's winding and magnetic field inside the iron core, also in terms of permissible thermal stress. The load excitation of the stator winding was carried out by setting the current density and its frequency [14].

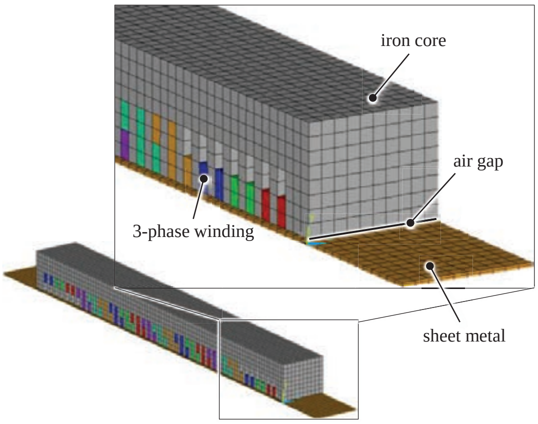

Fig. 11. Symmetry 3D simulation model of the electromagnetic feeder

Since the sheet metal acts as an active secondary part, its electric and magnetic properties influence the achievable feeding forces. In Fig. 12 the influence of phase current frequency on feeding force is shown, by which the magnetic field's relative velocity is adjusted. There exists a strong dependence of the forces on the frequency which is characteristic for asynchronous motors.

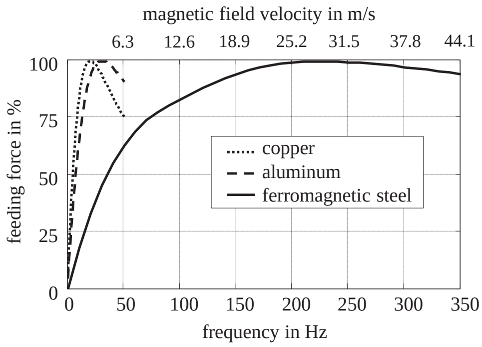

Fig. 12. Simulated force-frequency dependence for a sheet cross section of 100x2 mm² for different materials

The inductive properties of the sheet metal cause an optimal operating point where a maximum feeding force is achieved. At this frequency the magnetic field amplitude is located inside the sheet metal perpendicular to the current amplitude caused by the current phase shift. Using well conductive sheet metals, such as aluminum or copper, significantly lower relative velocities are required in order to set the optimal operating point. High frequencies, as needed for ferromagnetic steels, lead to higher power consumption and thermal losses in the stators and therefore to lower energy efficiency.

3.2. Experiments and Validation

The investigations regarding the achievable feeding forces by means of the electromagnetic feeder were carried out by simulations as well as experiments. For this purpose, a demonstrator of the electromagnetic feeder was constructed and manufactured at the IFUM (Fig. 13).

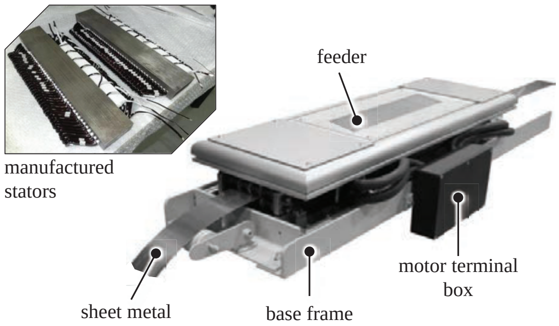

Fig. 13. Manufactured feeder

An extract of the feeder's technical parameters is listed in Table 1:

Table 1. Technical parameters of the electromagnetic feeder.

parameter	value
rated voltage	400 V
rated current / max. current	30 A / 50 A
rated power	15 kW
rated frequency (serial stator connection)	140 Hz

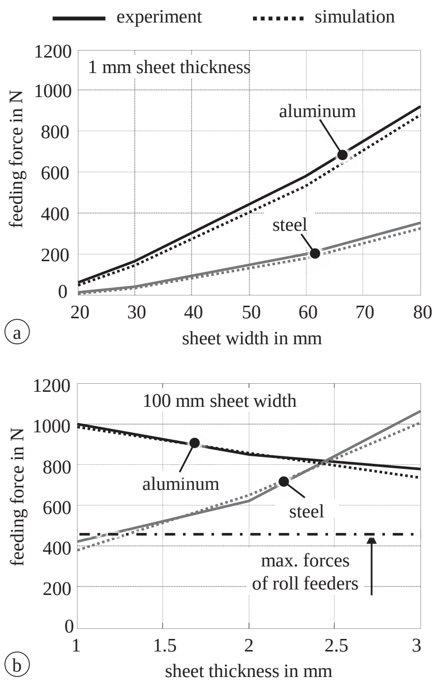

Fig. 14. Measured and simulated feeding forces under variation of sheet width (a) and thickness (b)

In order to determine the feeding forces, a test bench was manufactured. Within the experiments the phase current and its frequency were measured. The measured values were added to the simulation model in order to determine the winding excitation. The simulation and experimental results for ferromagnetic steel as well as aluminum are shown in Fig. 13. In addition the sheet geometry was varied in width from 20 to 100 mm (Fig. 14a) and in thickness from 1 to 3 mm (Fig. 14b). In all studies the feeder was excited up to its rated power of 15 kW.

In general, the deviation is below 10 %. The maximum feeding forces are partially more than 1000 N, depending on material properties and geometry of the sheet. In comparison, roll feeders of the same size achieve a maximum of less than 500 N [15].

As expected, an increased sheet width leads to higher forces in accordance with Eq. 1. In contrast, a variation in sheet thickness leads to different force progressions for aluminum and steel. This can be explained by the different properties. Due to the non-magnetic properties of aluminum the magnetic resistance rises with increasing thickness. Inside the air gap the magnetic forces decrease and consequently so do the feeding forces. In contrast to aluminum, ferromagnetic steels feature a high permeability. Therefore, the magnetic field is uninfluenced. The increased thickness causes higher currents inside the sheet metal and the feeding forces rise, as shown in Fig. 14b.

The new electromagnetic feeder offers a high potential to exceed the feeding rates as well as the efficiency of mechanical feeders. Due to a higher acceleration capacity, non-productive time can be minimized and productivity increased. At the same time, damage of the sheet surface can be avoided, feeder components are not subject to wear and maintenance costs will not be caused.

4. Conclusion and Discussion

In this paper two different systems offering great energy savings potential in metal forming processes were presented. A brief overview of the research on a new efficient drive concept for servo presses showed the advantages compared to conventional servo presses. Upcoming tests with the newly designed demonstrator should confirm the potential of the power-split press drive and allow an evaluation of the energy savings potential.

The second part of this paper shows the results of the research on an electromagnetic sheet metal feeder. Extensive studies on the relevant characteristic values were discussed. Both systems have great potential and are a step towards a more powerful and efficient production.

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