Mechatronic Systems in Forming Technology

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ABSTRACT

In daily life we experience a trend towards a growing diversity of products and as a consequence lower batch sizes in production. With regard to forming technology this leads to the necessity to vary the kinematics of the slides of forming machines to meet the demands of the forming processes without reducing productivity. In order to meet this challenge, mechatronic systems are increasingly employed in forming technology since mechanical systems are unsuitable for realizing variable kinematics of moving machine components.

Concerning sheet metal forming today, the implementation of servo-electrically driven presses offers the feature to vary the path-time-characteristic of the slide, adapting it to the material flow inside the toolset while forming the workpiece. Improving the process control, productivity and energy consumption per produced part, engineers are also faced with ambitious mechatronic systems and challenges in power management, depending on the mechanical and electrical design of the machine.

Not only the performance of forming machines, but also the capability of periphery devices concerning the output and handling of sensitive material can be raised by utilizing mechatronic systems.

In this contribution advances in forming technology with regard to the application of mechatronic systems in press drives and sheet metal feeders are presented.

1 INTRODUCTION

Mechatronic is a rather new idiom describing the coaction of mechanical and electrical engineering as well as computer science [1]. One reason for its origin may be the standstill in developments relating to mechanical systems to realize variable kinematics of moving components in machines, as they are often needed in production technology. *Fig. 1* shows a transfer press built around 1900, driven by means of mechanical devices only. Process adapted kinematics were realized by means of cam disks. This kind of machine doesn’t look much different today. It provides a high process reliability and defies all competition producing high and very high quantities of workpieces.

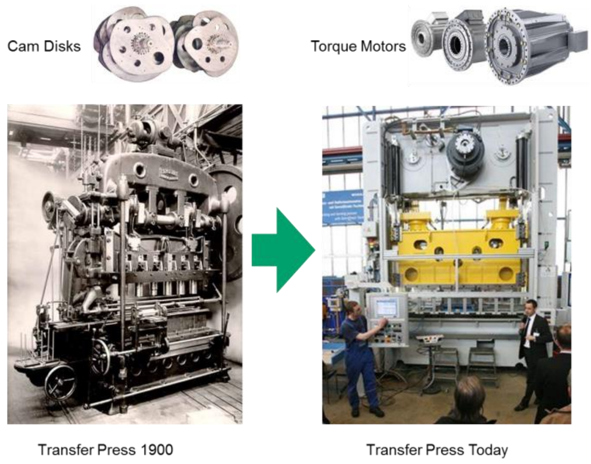

Fig. 1: Transfer presses and drive components (Schuler / Siemens)

In daily life the diversity of products is growing, leading to lower batch sizes in production. The necessity to adapt the specific kinematics of the slide and the transfer device when varying the tool set leads to the problem that press drive parts such as cam disks or lever arms have to be modified using transfer presses like the one mentioned above. This requires setup time.

Using mechatronic drive systems and modern control techniques the kinematics can be varied on the users interface. For this reason cam disks are increasingly replaced by servomotors.

Even components in the direct power train of sheet metal forming presses can be driven by means of permanently excited torque motors controlled by modern power electronics in certain cases today.

1.1 THE CHALLENGE

The kinematic of the slide has the most significant influence on the properties of the produced parts. Varying characteristics of forming processes require an adaption of path-time-curves of the slide (for a defined process there exist more or less appropriate kinematics for the upper tool part which is fixed to the slide).

Fig. 2 contains examples. For coining e. g. it is convenient to realize a small movement near the Bottom Dead Center (BDC). For cutting processes there exist various optimal kinematics. For rather thick sheets it may be a slow movement, for thin sheets high speed cutting is a favorable alternative. Deep drawing preferably requires a linear path-time-curve, perhaps with a small relief to avoid a too strong impact of the blank holder on the sheet metal. Forging is best with a fast movement to avoid a long dwell time since the dwell time has a strong impact on the tool lifetime in hot bulk metal forming.

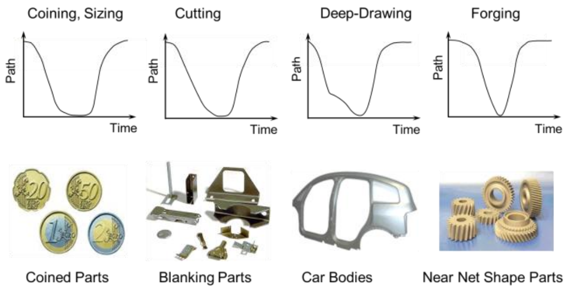

Fig. 2: Process-adapted kinematics [2]

To realize these process-adapted kinematics there exist several principles on the base of leverages and hydraulic power trains [3]. Servo-electric press-drives are certainly the latest and most flexible solution.

2 SOLUTIONS

Servo-electric press drives have been developed due to the disadvantages of hydraulic systems (low stiffness and efficiency, toxicity and flammability of oil). The most obvious way to build such a machine is to take an eccentric press (*Fig. 3*, left side), put the flywheel aside and replace the asynchronous motor, mostly by a permanently excited synchronous motor (*Fig. 3*).

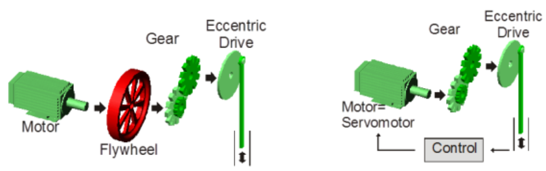

Fig. 3: Eccentric press versus servo-electric driven press

Such a concept provides the advantage to vary the slides kinematic by means of accelerating or decelerating the motors rotational speed. The dynamic, force- and working-capacity depend on mechanical and electrical design. Cosinus-like movements can be realized as well as toggle-joint characteristics, shortened heights of stroke by means of oscillating rotations, dwells to insert secondary manufacturing steps etc.. The electrical side can be designed similar to *Fig. 4*.

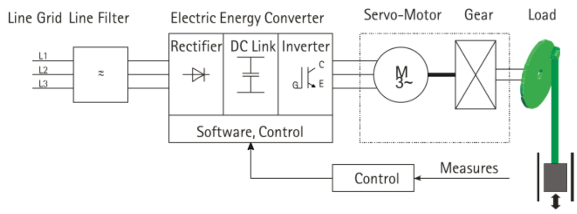

Fig. 4: Electrical design

2.1 COUPLING MECHANISMS

The mechanical coupling mechanism between motor and slide has a significant influence on the needs of dimensioning the motor, cables and potential energy storages due to its gear ratios and inertias. In order to specify this more clearly Behrens et al. compared various coupling mechanisms [4]. The slide was not modified in all investigated variants. The coupling mechanism between motor and slide was modified according to servo-electric press drives existing on the market. Due to the high inertia of the variant with transverse shafts (*Fig. 5, left side*) the inertia forces are higher than in the drive concept with a longitudinal shaft (*Fig. 5, middle*). The inertia using a threaded spindle drive (*Fig. 5, right side*) is even smaller than the one of the longitudinal shaft. The gear ratio between the motor's rotation and the movement of the slide is similar to the cosinus at the eccentric drives and equals the one at the threaded spindle drive.

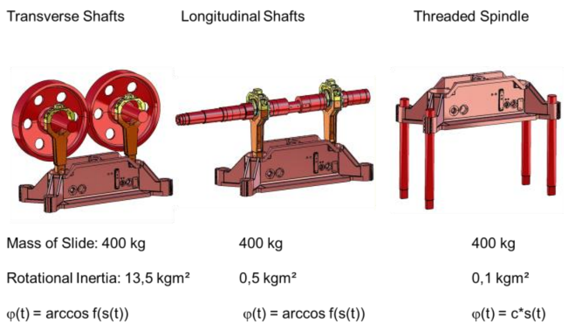

Fig. 5: Coupling mechanisms for servo-electric driven presses

A small inertia is positive in general because the electrical power consumption increases with the mechanical inertia. The influence of the inertia on the dimension of the motor etc. as well as the influence of the gear ratio depends on the desired path-time-characteristic. In any case this is an up-and-down-movement of the slide. To a certain extent it is more or less a modification of a cosinus-like movement (compare *Fig. 2*).

Due to the fact that the quality of the most chipless formed sheet metal parts is defined in a deep-drawing process, a slide kinematic convenient to such a process was chosen as a study object. For this path-time-characteristic (*Fig. 6,* top) the influence of the construction (inertias, gear ratios) on the moment- and power requirements to accelerate or decelerate the moved rotating and oscillating parts was simulated (*Fig. 6,* middle and bottom). Process forces were not adopted. The concept with transversal shafts exceeds the required drive moment and also the required power in comparison to other concepts by far. Also the power peaks to be provided from the line grid or an energy storage are around 10 times higher.

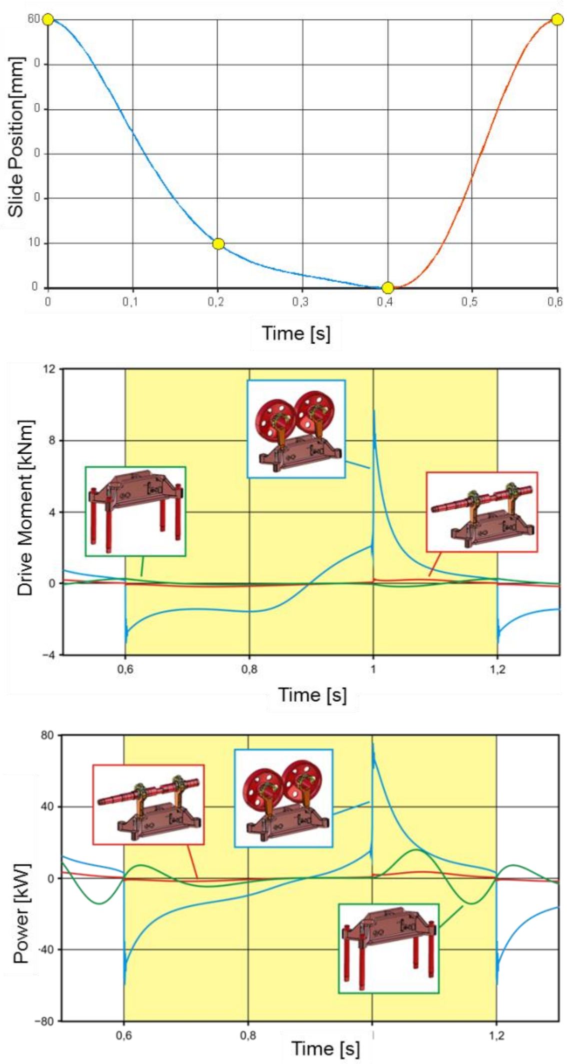

Fig. 6: Moment and power consumption to realize a specified slide kinematic

It can be stated that the maximum moment and power requirement will occur when the slide is moved upwards. This is the tribute to be paid to the high accelerations, but inevitable to raise the mean stroke rate. In fact from a certain stroke rate on, the needs of moment and power during the return stroke are the design specifications in construction. In the case of the chosen example the drive concept with a longitudinal shaft performs best with regard to the moment and the power, even better than the threaded spindle drive. The reason for this is the non-linear gear ratio of the drive between 0 and 1, that enables a constant speed of rotating parts (no inertia forces), if a cosinus-like movement of the slide is performed. The desired kinematic is similar to the cosinus curve to a certain extent in this case (like most for forming processes suitable kinematics for the slides of forming machines, *Fig. 2*). In addition to construction and the desired slide kinematic defined by means of sampling points also the applied interpolation method between these points influences the power requests to the motor, cables and to probably installed energy storages like supercaps or standby flywheels [4] and also their dimensions. These devices are expensive, lead to energy losses due to multiple energy conversions and should be designed as big as necessary and as small as possible.

2.2 POWER SPLITTING (DRIVE CONCEPT)

To benefit from the advantages of a flywheel press drive as an integrated energy storage without missing the flexibility of servo-electric drives, current research deals with a power splitting drive combining both. Fig. 7 shows a drive concept with two motors transmitting a rotation to a differential gear.

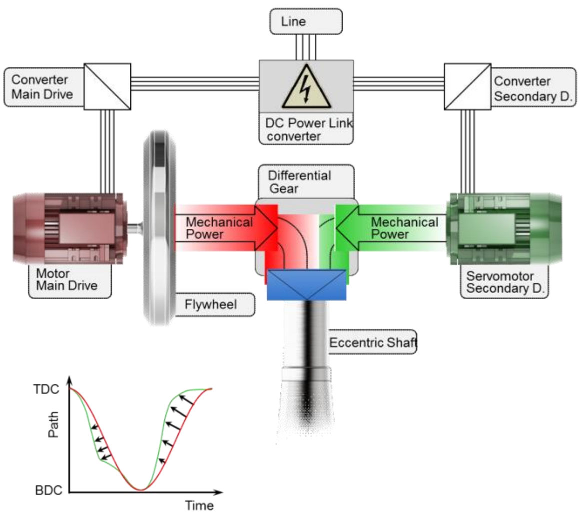

Fig. 7: Combined flywheel- and servo-electric drive

The major percentage of the required energy is transduced from a motor via a flywheel to the differential gear and the eccentric drive (main drive in Fig. 7 [5]). A secondary drive containing a rather small dimensioned servomotor only transmits the energy to vary the slide kinematic from the cosinus-like curve. The rotation speed of the eccentric shaft depends on the difference between the main and secondary drive. If the secondary drive stops, the eccentric shaft rotates with constant speed and the slide moves similar to the cosinus. If the secondary drive rotates as fast as the main drive, the eccentric shaft stops.

Both drives are electrically connected via converters, having a line connection in the DC-link. Thus, required power-peaks in the secondary drive can be supplied from the flywheel.

2.3 PERIPHERY / FEEDERS

Not only drive systems of forming machines can be improved by means of mechatronic systems but also periphery devices such as feeders. Feeders are devices to transport the sheet metal to be processed into the machine or into the die set, respectively. In general they are equipped with mechanical grippers or rolls in contact with the sheet metal and moving it in adjustable steps between the strokes of the slide into the die set. In normal applications the roll feeder is standard (*Fig. 9*, top).

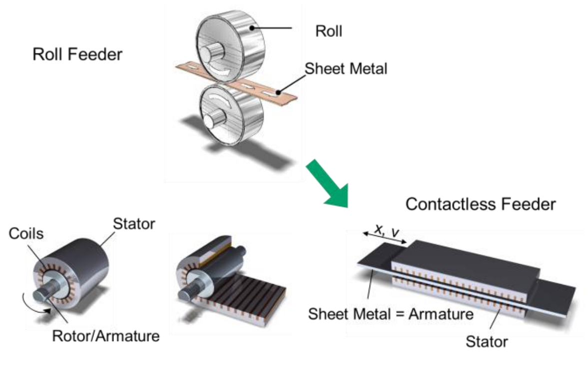

Fig. 8: From rollers to contactless feeders

High stroke rates can be realized and the feed length is not limited. On the other hand high contact pressures, probably damaging the surface of sensitive sheet materials, are a disadvantage. Only rarely feeders with segmented rolls are used. Here even higher stroke rates can be realized due to the lower inertia of the rolls, but the feed length is limited according to the segment length. A solution to avoid slipping between the rolls or grippers and the sheet metal due to insufficient friction forces is a contactless feeder based on electromagnetic forces [6], [7]. Thus, surface damages as a result of high contact pressure can be avoided. The contactless feeder can be imagined as a decoiled asynchronous motor, in which the rotor respectively armature is replaced by the sheet metal. The stator consists of two laminated iron cores filled with a three-phase winding. Each winding is charged with an AC current, which is phase-shifted to the currents in the other two windings. By this an electromagnetic wave is induced in the air gap between the stators, traveling through the stators with an adjustable frequency. This magnetic traveling wave induces circular eddy currents in the electrically conductive sheet metal. Analogous to an asynchronous motor the interacting magnetic fields of the eddy current in the sheet metal and the traveling wave in the stator apply a translational force to the sheet metal according to the Lorentz law (*Fig. 9*).

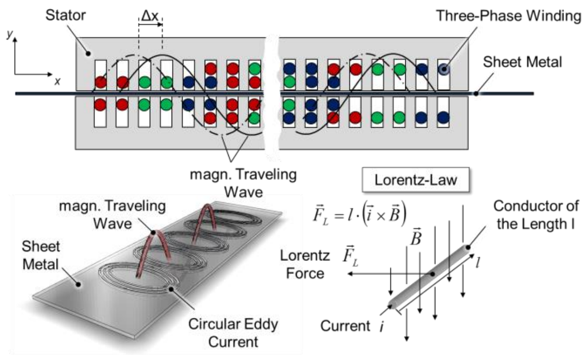

Fig. 9: Traveling magnetic field

Though the performance of the contactless feeder depends on the conductivity of the fed material it is possible to increase the feeding forces and velocities to nearly the double values of conventional feeders in certain cases without damaging the material surface.

3 SUMMARY

Mechatronic systems increasingly find their way into production technology. In recent years they were also integrated in forming machines and periphery equipment, where mechanical parts have to be moved under high forces. By means of servo-electrically driven presses the path-time-characteristic of tools and dies can be adapted to specific forming processes. Using these systems productivity can be raised by shortening the time for return-strokes. Periphery devices around the press can also be optimized regarding output and material handling by mechatronic systems.

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