Concept of a Hybrid Linear Press Drive

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ABSTRACT

Developments in the field of linear drive engineering allow the application of linear drives as main drives in metal forming machines. Linear drives are capable of realizing highly variable motion sequences, as they are usually applied as direct drives. The main disadvantage is the relatively low achievable process force. Due to the direct drive principle, there is no option to increase the process force with the help of a transmission gearing. At the IFUM, a novel drive train is investigated to overcome mentioned disadvantage. The new drive train consists of compact linear motors in combination with high performance electromagnets. With this kind of drive, the field of application for linear driven presses can be extended as the electromagnets increase the available process force near the bottom dead center. In this region, high forces are convenient to accomplish cutting and coining processes. Based on the previously presented dimensioning a mechanical construction for a press prototype as well as a control concept have been developed. The main aspects are the compensation of the relatively long reaction time of such strong electromagnets and the synchronization of both drive systems as well as the synthesis of a sufficiently rigid press frame. The operating principles of both drive systems as well as the mechanical construction and the control concept for the prototype are described in this paper.

1 INTRODUCTION

At the IFUM an innovative hybrid press drive is investigated. The hybrid press drive consists of linear motors and high performance electromagnets. The linear motors are applied to realize the stroke and to provide a process force of up to 25 kilonewtons throughout the whole stroke as needed for deep drawing, see fig. 1. The electromagnets provide an additional combined force of about 100 kilonewtons within a range of one millimeter around the bottom dead center. By application of the additional force the press is enabled to carry out processes that demand high forces such as coining and cutting, see fig. 1.

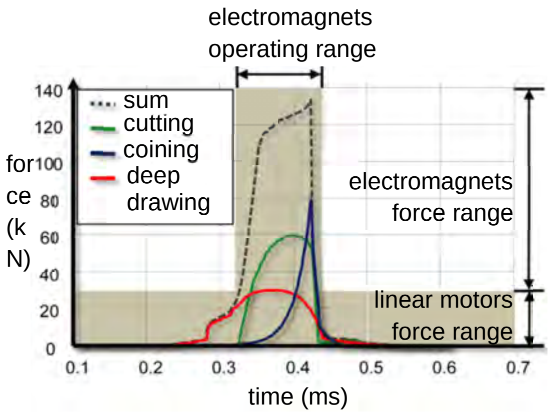

Fig. 1 Force ranges for different forming processes

The shown force range enables the manufacturing of complex workpieces that accompany said processes within the press prototype. An example of a workpiece that is produced through a combination of multiple forming processes is illustrated in figure 2.

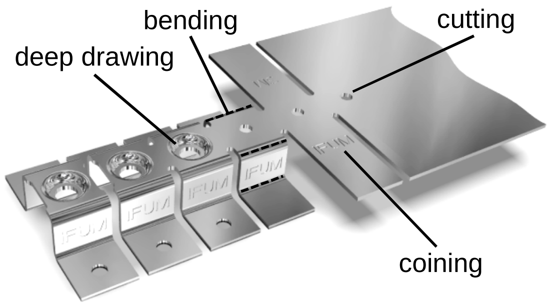

Fig. 2 Example workpiece accompanying multiple forming processes

The benefits of the hybrid press drive are that it is considerably smaller than conventional presses that are usually utilized to produce workpieces of that kind and that it is able to achieve higher stroke rates in combination with more flexible kinematics.

2 PRESS PROTOTYPE FOR THE HYBRID PRESS DRIVE

Following the initial dimensioning of the electromagnets and the linear motors which has been described in detail in [1] a press prototype is currently realized. It is illustrated in fig. 3.

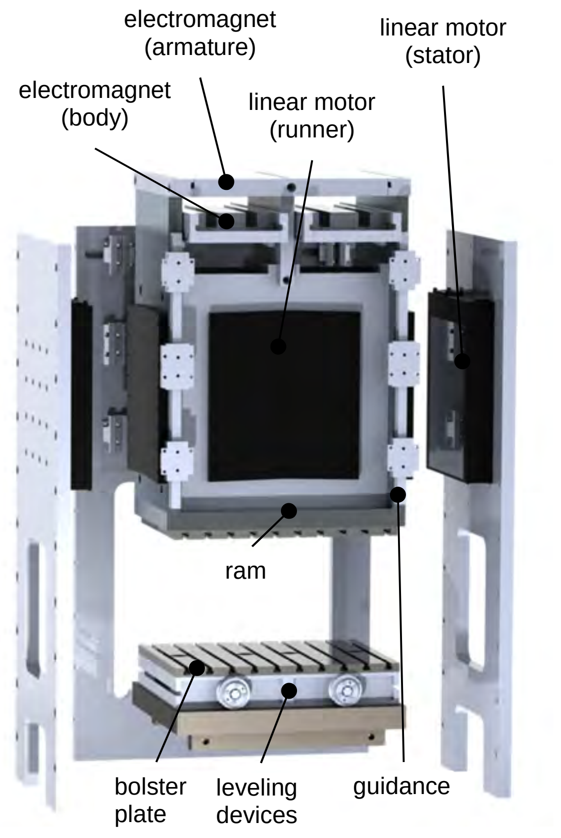

Fig. 3 Exploded view of the press prototype

The press prototype serves as proof of concept for the hybrid press drive. An analysis of the desirable kinematics and process forces led to the requirements of the drive train and the press body. The press prototype will have a footprint of 500 x 700 millimeters. The prototype could be utilized economically for bending, deep-drawing, cutting and coining processes. The kinematics is more flexible as with conventional presses with comparable key data.

2.1 LINEAR MOTORS

As with rotational AC motors, linear AC motors are composed of an active part that is called stator and a passive part, the runner, see fig 4.

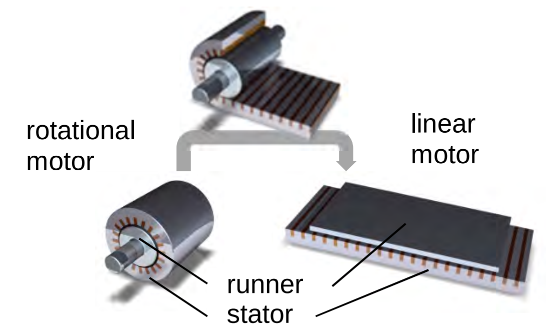

Fig. 4 Correlation between rotational and linear motors

The runner of a synchronous linear motor is equipped with permanent magnets. The stator consists of a three phase winding that is situated within a magnetic body. Following the dimensioning [1], four permanently excited synchronous linear motors from the 1FN3900 product range by Siemens have been chosen for the press prototype. From the commercially available linear motors, they provide the highest force density, which results in a small and with that a rigid mechanical construction of the ram and the press frame respectively.

2.2 ELECTROMAGNETS

An electromagnet consists of a body, which is equipped with one or more coils for the magnetic excitation. A passive armature is needed as counterpart that is attracted by the electromagnet while it is excited. The electromagnets for the hybrid press drive have been dimensioned with the help of numerical simulations. The dimensions of the electromagnet body and the armature as well as the needed current have been calculated. The two electromagnets are dimensioned to conduct a combined force of 100 kilonewtons within a range of 1 mm around the bottom dead center. A current of 20 amperes is needed to generate that force.

Because of its inductance, an electromagnet cannot provide the nominal force immediately after its activation. The designed electromagnets for the press prototype need approximately 200 milliseconds to generate the nominal force, if the nominal voltage is applied. The best way to shorten that time is the application of a method called over-excitation. For the activation process a higher voltage than it would be necessary to reach the steady state force is applied for a limited time [2]. This can be realized by means of a power converter coupled with a current controller to adapt the voltage dynamically. Such a current controller was simulated in Ansys Classic APDL. The simulated activating behavior with an air gap of 1.5 millimeters as well as the deactivating behavior with an air gap of 0.5 millimeters is graphed in fig. 5.

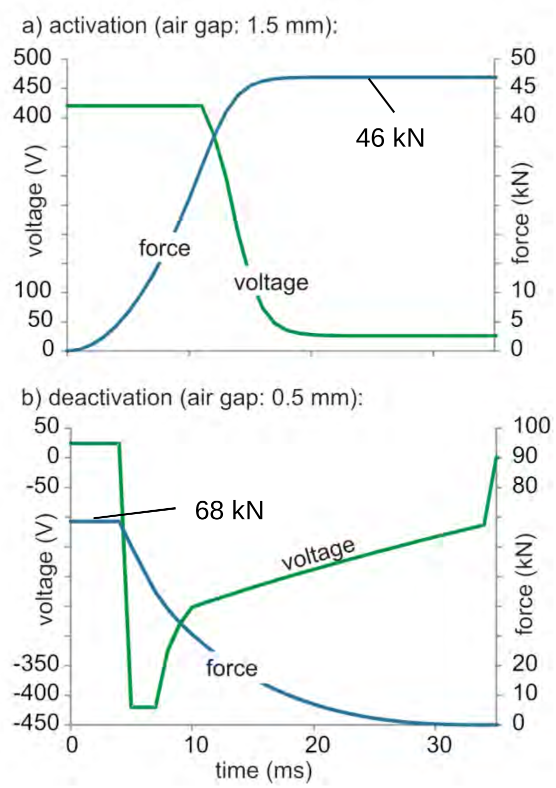

Fig. 5 Simulated activating and deactivating procedure with applied over-excitation

By means of the over-excitation with up to 420 volts the nominal force can be reached within 20 milliseconds (fig. 5 a), at the beginning of the electromagnets working range, which is located one millimeter before the bottom dead center (while the air gap is 1.5 millimeters). If the ram is situated at the bottom dead center the air gap is reduced to 0.5 millimeters. Accordingly, the electromagnetic force caused by the nominal voltage is increased to 68 kilonewtons (fig. 5 b). With the help of the over-excitation, this time with a negative voltage peak, the electromagnetic force is decreased to about ten kilonewtons within 20 milliseconds, so that the linear motors are then able to raise the ram against the remaining electromagnetic force.

2.3 DESIGN OF THE RAM

The ram is a critical part for the dynamics achievable with the hybrid press drive. Its mass limits the achievable stroke rate and the flexibility of the kinematics. The ram is equipped with the runners of the linear motors, the armatures of the electromagnets and the guidance rails. These parts are more lightweight than their active counterparts and do not contain moving wires that could get damaged. The rams shape is highly dependent of the said parts that have to be mounted on it. The active counterparts of those components are mounted in the press frame.

The aim is to gain a stroke rate of 500 strokes per minute over a stroke of 50 millimeters with cosine-like kinematics. A lightweight ram construction is mandatory for that reason. Different constructions and materials have been evaluated. If the ram was manufactured from steel, the base sheets have to be very thin in order to be lightweight enough to achieve the desired stroke rate. Subsequently, their thickness would not be sufficient to securely install the runners of the linear motors. Instead, if an aluminum alloy is used, the thickness of the base sheets can be increased which allows a solid connection between the runners and the ram. Additionally, the stability of the structure is increased while the mass is decreased. Guidances with zero clearance are used to achieve a rigid guidance within the stroke path. To realize a closed-loop kinematics controller, it is necessary to steadily measure the distance travelled by the ram. For that reason, one of the guidances is equipped with an integrated measuring system. That is to save space within the machine structure and to simplify its installation compared to a stand-alone measuring system.

To find a well suited shape, finite element method analyses have been carried out for eight different ram shapes. The varieties differed in the disposition of the parts to be mounted and in the shape of the ram itself. The first selection criterion was the lowest stresses and with that the lowest deformation of the ram structure at nominal force with centric as well as excentric loads. Secondly, the eigen frequencies of the different shapes were calculated. Finally, a shape was found whose stresses were relatively low and which has an eigen frequency band which is not expected to be excited by forming operations, cutting impacts or the stroke rate respectively. The most compact shape best satisfied the given criteria. It has a mass of 215 kilograms including all the mentioned attachment parts.

2.4 DESIGN OF THE PRESS FRAME

As the mass of the press frame is not essential for the achievable stroke rate it is carried out from steel. According to the previous explanations, the active parts (measuring system and brakes) as well as the active parts of the drive units are mounted in the head end of the press frame. In addition to the head end the press frame comprises an adjustable bolster plate, see Figure 1.

To set the position of the bolster plate for various tool heights and to correct the position of the electromagnets air gap, two adjustable leveling devices are incorporated between the table and the carrier plate. The leveling devices facilitate an adjustment range of ten millimeters. Further adjustments can be realized by means of spacer plates.

3 CONTROLLING CONCEPT FOR THE HYBRID PRESS DRIVE

To control the press prototype, a hybrid controlling system will be used. It is composed of two "DC-Master" units that power the electromagnets and a "SIMOTION"-Motion control system and the corresponding power units to feed the linear motors. The topology of the controlling system is illustrated in fig. 6.

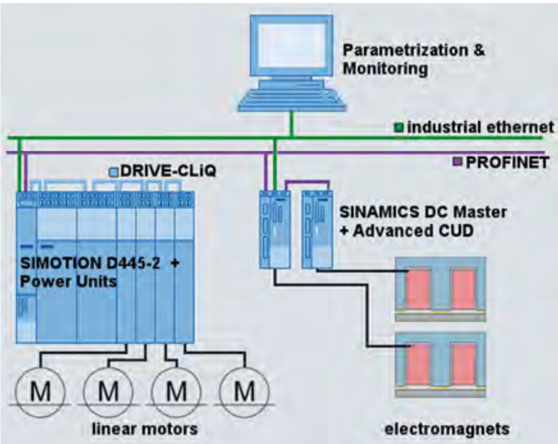

Fig. 6 Hybrid controlling system for the press prototype

The Simotion system allows the creation and use of user-written programs. For this purpose, a computer that is equipped with the proprietary Simotion Scout software is connected to the Simotion via industrial ethernet. Simotion Scout is an integrated development environment allowing the use of the specific functions of the Simotion system. The computer is not mandatory to operate the press prototype. It is needed only to adapt the linear motors trajectories or the user programs respectively. The Simotion is stocked with multiple ethernet ports that can be projected freely to common ethernet standards. To communicate bidirectional with the DC-Master units one of those ports is assigned as PROFINET port. The DC-Master units are equipped with an "advanced CUD" that adds PROFINET support. The DC-Masters manage the current control for the DC electromagnets independently while they receive their target values from the SIMOTION unit which controls and monitors the motion and positioning states of the ram by means of the integrated guidance measuring system. As the DC-Masters intended use is the supply of DC-Motors, some modifications have to be made to enable the direct current control [3]. It was tested and verified that they are suited for this purpose with the help of a simple test rig comprising of a test electromagnet, a modified DC-Master unit and a force measurement system. The results are graphed in fig. 7.

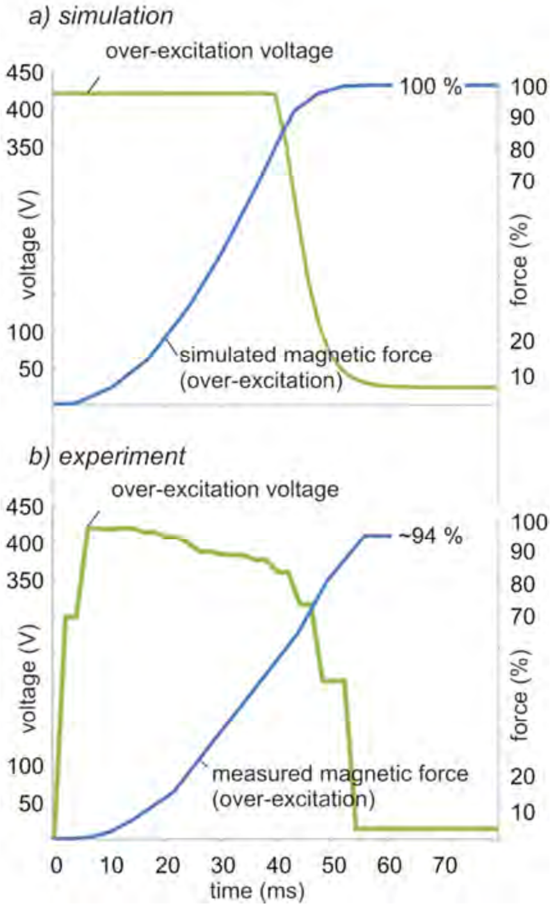

Fig. 7 correlation of the force progression between the simulation and the experiment

As shown in the diagram the simulated and the measured force progressions are similar. It confirms the suitability of the introduced controlling concept. Therewith, a maximum stroke rate of approximately 500 strokes per minute with the linear motors at full stroke can be realized with an added delay of approximately 20 milliseconds for each stroke if the electromagnets are utilized. The halt occurs, because of the inductance of the electromagnets. For the best performance in the field, the electromagnets are activated before the ram reaches the bottom dead center, so that only the deactivation delay adds a halt to the motion sequence of the ram. For this reason, the actual currents in the electromagnets are transferred from the DC-Masters to the Simotion. While the ram is situated in the bottom dead center and the electromagnets are active, the motion sequence is paused temporarily. As soon as the force that is proportional to the current in the electromagnet has decreased sufficiently, the motion sequence is continued.

4 CONCLUSION

Following the dimensioning of the drive units a mechanical construction for the linear hybrid press prototype has been carried out and a control concept was developed. The press prototype facilitates a stroke of 50 millimeters and is able to conduct forces up to 25 kilonewtons throughout the whole stroke. At one millimeter before the bottom dead center an additional force of about 90 kilonewtons can be utilized that is generated by the electromagnets. It was tested and verified that the chosen DC-Master units are able to control the current in the electromagnets and that there is little deviation regarding the force progression between the simulated and the real current controller.

5 ACKNOWLEDGEMENT

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6 REFERENCES

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