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Direct Drive of 25 MN Mechanical Forging Press

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Abstract

In the branch of forging presses there are new ones with direct drive. Our aim was to find out its possibility and to validate its properties and functionality. Mechanical forging single point press with a nominal force of 25 MN is selected for the example of direct-drive – this is a more powerful than was ever produced. The proposed direct drive is solved by pair of torque motors. These are connected with eccentric shaft via a gear drive, because of need to reduce speed. The paper gives the engineering process, including determination of the time of the stroke. We tried to discus a questions about efficiency in this paper.

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Keywords: forming machine; direct drive; forging; torque motor

1. Introduction

[1], [2]

The issue of direct drive of forming machine is in focus in the Centre of research in the machine design (CVTS) at the Faculty of Mechanical Engineering University of West Bohemia in Pilsen for a long time. The large-scale deployment in the crank presses design this drive collide with poor performance and high cost of special torque motors and especially with the inability to quickly and adequately capacitive accumulation of electricity. Time progressed and the deployment of direct drive has become more available, although there still remains a question about its benefits.

An example of direct drive forging press might be Schuler GROUP press PK SDT 1600 [2], which is in operation in forge ŠKODA AUTO. Among the suggested advantages of direct drive belongs shortening of unproductive time,

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which is positively reflected in the productivity of the press (the number of strokes per minute). Another of the perceived advantages that connected with direct drive in general, is a reduction of energy consumption by removing components such as clutches, brakes, belt drive, etc.

Forging press Schuler PK SDT 1600 is a proof that technical solutions exist. Therefore we decided to project direct drive press with a nominal power of 25 MN (2,500 t). Our methods were quite simple. We prepared parameters of common 25 MN forging press and then we made design calculations for its drive.

At the end of this paper we tried to discus energy efficiency which should be better for direct drive (according to producers proclamations).

2. Forging press 25 MN

[1], [2] , [3]

Before creating a specific technical assignment we made market research, where we focused on current and historical forging presses with a nominal force of 25 MN. Following parameters arose from the survey:

- Nominal force 25 MN
- Stroke 25 min-1
- Continuous operation at 60 min-1
- Ram stroke 350 mm
- Press shut 950 mm
- Connecting rod length 1275 mm
- Motor power (flywheel) 130 kW

For the purpose of determining the size of the drive we came out of the press SCHULER PK 1600 SDT. There is considered nominal angle α_j = 20 ° and rectangular shape of deformation characteristics (see Fig. 1). Rated angle corresponds to the useful stroke h_u = 12 mm.

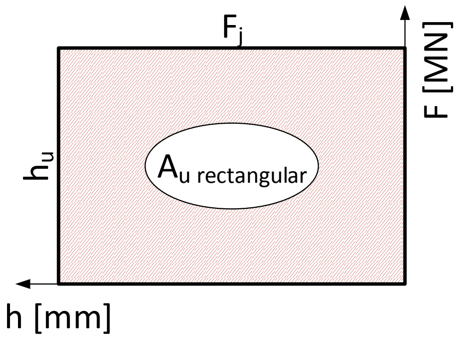

Fig. 1. Rectangular shape of deformation characteristic.

Useful work equal to:

$$A_u = F_j \cdot h_u = 25[MN] \cdot 12[mm] = 300\ kJ \tag{1}$$

2.1. Maximum torque at eccentric shaft

To ensure nominal force with a certain reserve (for example needed for friction loses) it is considered force overload of 20% which corresponds to the force F_{MAX} = 30 MN.

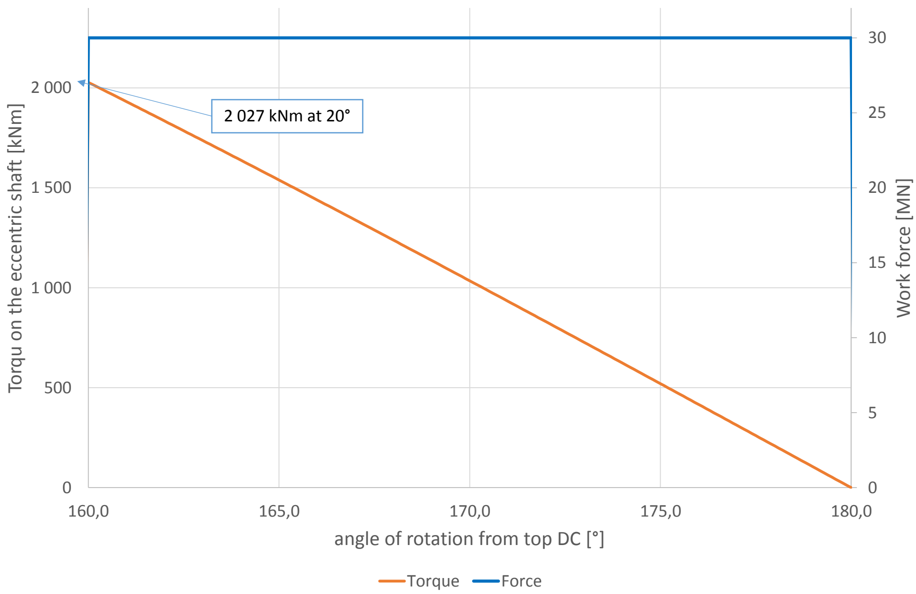

Fig. 2. Progress of work force and needed torque.

For deriving of the required maximum force is to needed to act torque M_{max} = 2027 kNm with the eccentric shaft. Concrete progress is shown in the previous figure (Fig. 2).

Specified torque does not affect losses caused by friction between the eccentric shaft and putting it in the machine frame.

2.2. Choice of drive motor

The following proposal is made for two engines OSWALD TF36.120, whose parameters are as follows (Fig. 3):

- Number of motors n = 2 pcs
- Nominal power one motor P_n = 504 kW
- Installed power P_{n_instal} = 1,008 kW
- Nominal speed n_n = 500 min-1
- The nominal torque M_n = 9.6 kNm
- The maximum torque M_{max} = 27 kNm
- Maximum speed n_F = 750 min-1
- Maximum mechanical speed n_{max} = 1000 min-1
- Motor overload p = 1.5
- Motor weight m = 1750 kg

If we consider the operation of engine with an overload, the maximum torque M_{max} reached at engine speed:

$$n_{M\max} = \frac{60}{2\cdot\pi}\cdot\frac{p\cdot P_N}{M_{\max}} = \frac{60}{2\cdot\pi}\cdot\frac{1{,}5\cdot 504}{27} = 267{,}4\ \text{min}^{-1} \qquad (2)$$

To achieve the required torque M_{max} needed to induce nominal force there is need to use transfer with ratio:

$$i = \frac{M_{MAX}}{n \cdot M_{\max}} = \frac{2027}{2 \cdot 27} = 37{,}55 \tag{3}$$

At maximum motor speed eccentric shaft will rotate at speeds:

$$n_{MAX} = \frac{n_F}{i} = \frac{750}{37{,}55} = 19{,}98 \text{ min}^{-1} \tag{4}$$

At maximum motor speed with no overload n_F there is available motor torque (both engines):

$$M_F = \frac{60}{2 \cdot \pi} \cdot \frac{n \cdot P_N}{n_F} = \frac{60}{2 \cdot \pi} \cdot \frac{2 \cdot 504}{750} = 12{,}8 \; kNm \tag{5}$$

Eccentric shaft rotate speed corresponding to the maximum torque with overload is:

$$n_{MIN} = \frac{n_{M\max}}{i} = \frac{267{,}4}{37{,}55} = 7{,}1 \text{ min}^{-1} \tag{6}$$

Moment at maximum speed with overload converted to eccentric shaft has a value of:

$$M_{nF} = 2 \cdot M_F \cdot i \cdot p = 2 \cdot 12{,}8 \cdot 37{,}55 \cdot 1{,}5 = 1441{,}9 \; kNm \tag{7}$$

Previous calculations are summarized in the following chart (Fig. 3)

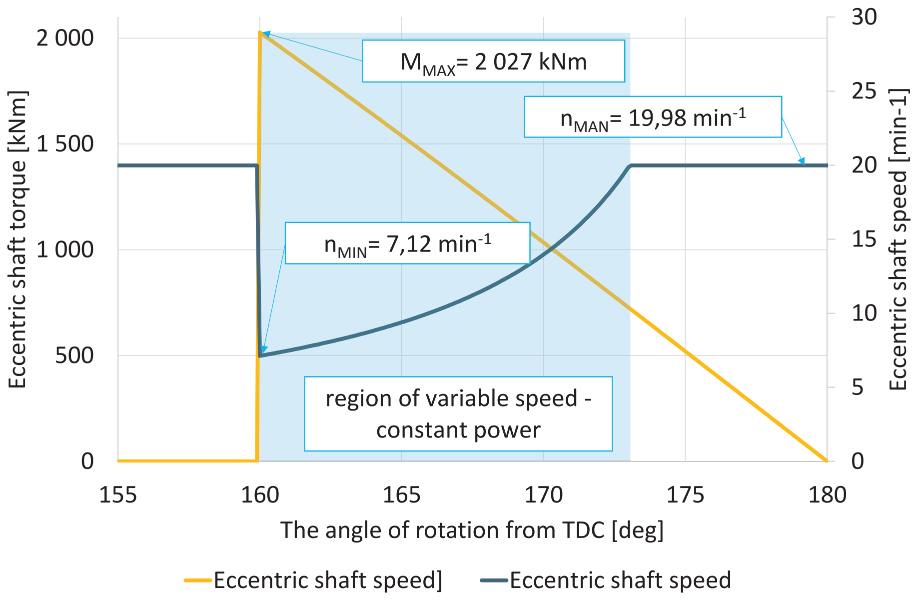

Fig. 3. Display of progression of the speed of eccentric shaft and of eccentric shaft torque depending on the position of the ram.

2.3. Determination of the time one revolution of eccentric shaft

Time one revolution of eccentric shaft is built on the assumption that the motor rotates in its maximum speed n_F = 750 min^{-1}. When applying technological operations will spin their maximum speed or the speed corresponding to the installed capacity (determined from the moment of overloaded motor).

Time calculation is performed for the maximum force F_{MAX} = 30 MN. This increased load covers the existence, not considered in the calculation, of passive resistance in the crank mechanism and power efficiency of transmission gearing.

Torque at the eccentric shaft is in the range of 160 ° to 173 ° higher than torque at the maximum speed M_{nF}. In this range maximum engine power with overload will be used - speed will decrease to n_{MIN}.

Time for one revolution of given assumptions is:

$$t_{F\_MAX} = 3{,}1\ s \tag{8}$$

This corresponds to the number of strokes per minute:

$$n_{oper} = \frac{60}{t_{F\_MAX}} = \frac{60}{3{,}1} = 19{,}3\ \text{min}^{-1} \tag{9}$$

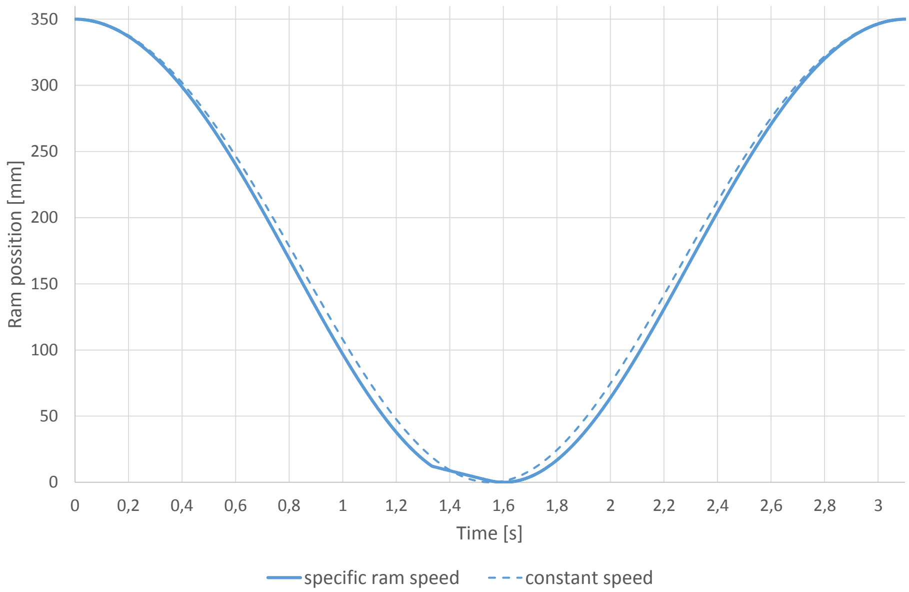

Fig. 4. Display position of the ram in relation to time for a specific stroke and uniform stroke at constant speed (from the graph it is clear that during the forming of reducing movement speed).

Figure (Fig. 4) shows the time dependence of the specific ram stroke (solid line). Steady stroke (shown for the same time speed; dashed line) shows a situation where the eccentric shaft rotation speed constant. For a specific stroke it is evident that the ram moves in its idle portion faster, but in areas where there is a forming operation (bottom dead center) its speed decreases.

2.4. Pendulum mode

Pendulum mode, for example, consists of limiting the rotation of the eccentric shaft in position 90° before and 90° after BDC (90 ° - 270 ° absolute), which always stops the drive and then change the sense of rotation. When considering the instant stop and instant start back, time of one stroke is:

$$t_{pendulum} = 1{,}6\ s \tag{10}$$

After that, the number of strokes is:

$$n_{oper} = \frac{60}{t_{pendulum}} = \frac{60}{1{,}6} = 37{,}5\ \min^{-1} \tag{11}$$

2.5. Transmission

Although it is a direct drive, which is usually seen as a direct connection with motor-driven component without the need for a transfer, if the crank forging press with an additional a transfer is unavoidable. Desired speed eccentric shafts are too low even for low-speed drives, such as torque motors.

In the previous text it is considered a pair of drive torque motors OSWALD TF36.120 whose nominal speed is 500 min-1, therefore transfer ration 37.55 is needed to determine the required speed.

From OSWALD motors could be used even slower ones, specifically OSWALD TF62.80 whose nominal speed is 200 $\min^{-1}$ and performance is similar to the proposed motor. Low speed is redeemed by its higher weight, namely a motor OSWALD TF36.120 weighs 1,750 kg and motor OSWALD TF62.80 weighs 3,550 kg, so the choice, despite the need for greater transfer it is relatively easy.

For such a large transfers shall be used a planetary gear, the connections could be as follows, see Fig.5.

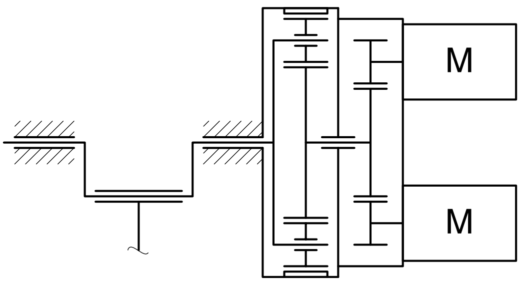

Fig. 5. Connection diagram of direct drive with planetary gear to eccentric shaft of press.

3. Energy management

[4], [5], [6], [7], [8], [9]

Direct drive consumes energy in dependence on the actual system requirements, and since it is not a small energy the torque motor cannot be connected directly to distribution network. Between the torque motor and the power grid must be inserted electricity storage device.

Methods of accumulation of electrical energy are several. Basic principles are two, which are further divided (selection):

- Chemical principles
  - Lead-acid, alkali and other (Li-Ion, ...) batteries

  - Supercapacitors
- The physical principles
  - Flywheels
  - Pumped storage hydro power plant
  - Energy storage based on compressed air

For the purpose of mechanical drive of the press it is essential to ensure an adequate energy supply (in this case, min. 300 kJ) and to ensure the possibility of rapid loading and unloading of the accumulator (in the order of 0.1 s). And of course there is a condition on the spatial low demands.

Usable storages are supercapacitors or the flywheel of the listed methods of accumulation.

The use the flywheel is essentially only a move of flywheel of conventional drive out of the machine. Yes, that will remove the coupling (energy loss) from the system, but this is compensated by the necessity of use of two powerful motor / generators when one is connected to the eccentric shaft and the second to the flywheel. The power transmission will always be dissipation.

3.1. System efficiency

One of the advantages of direct drive is its higher efficiency (lower energy loss). It is because of the remove of the clutch and brake and vice versa energy recovery is used. But there is no specific comparison. It does not exist or is not available publicly.

Some ideas of the efficiency of the drive is in creation based on the description of actuators, i.e. what happens between energy grid and eccentric shaft.

3.1.1. Loses in conventional drive

Conventional drive consists of an asynchronous motor (for 25 MN forging press it is about 150 kW), which can be powered via a frequency converter. The efficiency of such a motor varies around 92% depending on the speed [7]. The actual efficiency of converters can be up to 98%. V-belt transmission with the efficiency approximately 96% [4] is used on the press. Flywheel itself it is located on a separate shaft which is supported by roller bearings, whose efficiency is reported to be about 99%. Follow transfer gears whose efficacy is at least 98%. The next member it is drive clutch. The clutch is a place where there are significant energy losses of the slip at closing. Because the size of the loss depends on many parameters, it cannot be simply expressed as a specific percentage efficacy. Similarly to coupling it is difficult to describe brake that stops the moving mechanism at TDC.

3.1.2. Loses in direct drive

Direct drive consists of a special torque motor which indicated efficiency at rated speed and power is about 96% [3]. But efficiency will be lower at other than rated speed. The motor is powered via control unit which consists of voltage converters and rectifiers whose efficiency is about 98% and 99%. There are used transfer gears and planetary gear with efficiency 98% and 97% [5]. The drive itself is therefore more efficient. But when there must be added the influence of energy storage, the overall efficiency will be lower.

In the case of use of the supercapacitors it is necessary to count with their life of about 1 million cycles of charge and discharge efficiency in the range of 88-98%.

Accumulation in the flywheel is associated with the deployment of another powerful motor / generator with the necessity of considering the effectiveness of its control electronics as well as at discharge and during charging. And the line resistance losses are not negligible too. Sufficiently powerful flywheels are commercially available, bigger commercially used flywheel provides around 1,6MW for 10s [6].

The overall efficiency of such a drive is also not too high.

Conclusion

The purpose of this paper is to design the direct drive of the forging press with a nominal force of 25 MN. The impulse for the very existence of the solution was 16 MN forging press with direct drive produced by SCHULER GROUP. Within the program of our Centre CVTS where we deal with design of forming machines we have decided to design larger machine – 25 MN forging press with direct drive.

The result of our efforts is a rough draft of a possible of direct drive. In our proposal we used many simplifications, such as the crank mechanism do not consider passive resistance, but on the other hand, we consider a rectangular deformation characteristics from 20 ° before bottom dead center and possible force overload. We do consider our proposal to be real. The result is that it is possible to produce such a powerful press.

We ignored detail proposal of planetary gear, which certainly affects the production cost of the machine, or a particular way of accumulation of electric energy, which also affects the financial aspect, but also the spatial requirements of the new press.

We are trying to open a discussion about energy efficiency of both drive ways. There are too many benefits mentioned by direct drive machines' producers but there is no real comparison.

This Article shall not discuss the reported technological advantages of direct drive (about which we can doubt), nor we do not attempt to compare the financial performance of a particular solution, but we only outlines the specific solution for a medium to large forging presses.

Acknowledgements

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