INCREASING THE PRODUCTIVITY OF FORGING PRESS BY REDESIGNING OF A DRIVE

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Productivity of automated forging equipment can be improved by increasing the speed of the handling operations. It is necessary to increase the speed of a forging press to increase the productivity of the whole forging equipment. This higher speed can be achieved by adjusting the drive as presented in this article. The typical drive of a forging press consists of an electric motor, gears, energy accumulator (flywheel), clutch and a brake. For each working stroke, the required energy must be available which is taken from the energy accumulator so that the rotation speed can be reached within the permissible speed drop. This article describes the working stroke of the press, including the changes in speed and accumulated energy. Modifications to the press drive involve changing the electric motor and gear modification (belt drive and gearing). The result may be, apart from increased productivity, also weight savings (in the flywheel and electric motor) and financial savings (electric motor).

KEYWORDS

energy consumption, forging press,design,electric drive,energy accumulation

1 INTRODUCTION

Automation of forging equipment has reached a level where it is possible to carry out handling operations at higher speeds than forging machines are able to forge. This is the main reason why it is important to find a way to achieve a higher operating frequency for forging presses to increase productivity, and this is why we are working on this issue at the University of West Bohemia in CVTS (Research centre of forming machines). Previously, crank presses were designed for 25 working strokes per minute, which was absolutely fine for manual handling of workpieces. However, robots and automatic feeders are now used for handling, which are able to achieve a higher frequency of handling than experienced operators, and is the main reason why today's crank presses need a higher number of working strokes per minute to increase productivity.

The aim of this paper is to design modifications to a crank press drive to increase the number of work strokes by about 25 % by adjusting the crank press drive, and especially by changing the gear ratio or motor, with a minimum of changes to the crank press construction.

The smallest possible increase in energy consumption and the lowest possible increase to the weight of the machine is required in the new design.

2 TYPICAL MECHANISM OF CRANK FORGING PRESS DRIVE

A typical crank forging press is driven by an electric motor. The rotary motion of the electric motor is translated by a two-step gear box to the crank shaft. The crank mechanism typically has a one point connection, as shown in Fig. 1.

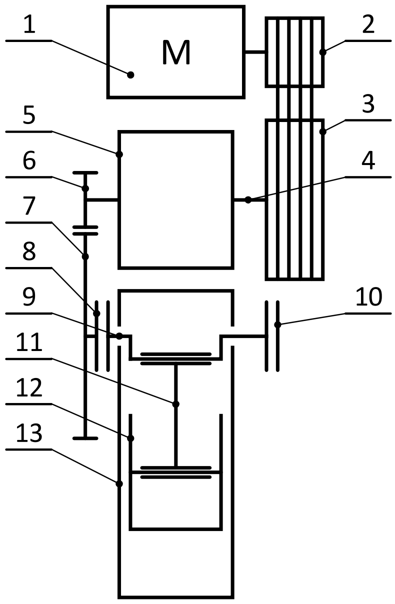

Figure 1. Diagram of typical crank forging press drive (1 – Electric motor; 2 – Drive pulley of motor; 3 – Drive pulley of countershaft; 4 - Countershaft; 5 -. Flywheel; 6 – Pinion of countershaft; 7 – Gear wheel of clutch; 8 - Clutch; 9 – Crank shaft; 10 - Brake; 11 – Connecting rod; 12 - Ram; 13 – Press frame)

A typical crank press, including drive, consists of these parts. The energy source of the crank press is an electric motor (1) which supplies power and speed through the first gear ratio to the first countershaft (4). The first gear ratio is transmitted by a belt. The main advantage of the belt is the ability of slippage during a drive crash. The drive pulley (3) and flywheel (5) mounted on the countershaft are used as energy storage which is used for the working stroke of the machine. The gear ratio between the countershaft and the crankshaft (9) is mediated by gear wheels (because big torquesare transmitted) and clutches (8). A brake (10) is located on the crank shaft. The brake is activated after the clutch is disconnected. The crank shaft is connected to the ram (12) via a connecting rod (11). All these parts are located in a frame (12).

3 ENERGY FLOW ANALYSIS

This analysis describes the working stroke of the machine. The technological operation is carried out in the bottom dead centre.

Figure 2 shows the typical torque of a crank shaft during the working stroke. The maximum torque valueis in the forming region before the bottom dead centre. Outside of the forming region, the torque is only for overcoming friction.

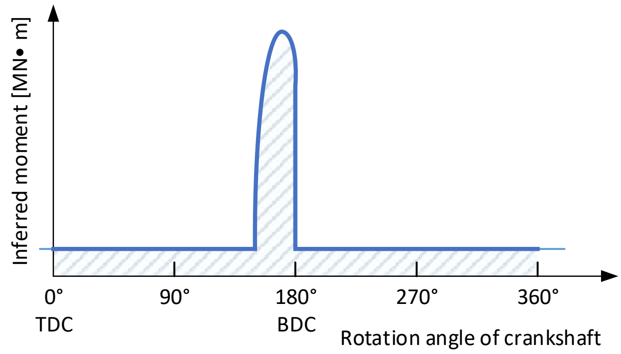

Figure2. Typical torque of crank shaft during work stroke

The next graph shows the energy which is accumulated in the moving parts of the crank press (Figure 3). The initial energy corresponds to the nominal speed of the drive with a disconnected crank shaft. Power is supplied by the electric motor during the entire working stroke.

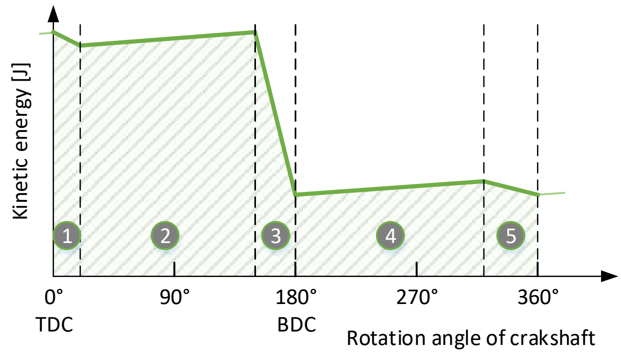

Figure3. Energy accumulated in moving parts of crank press (significant phase of stroke)

Rotation speed of the countershaft is shown in the last graph (Figure 4). The initial rotation speed corresponds to the nominal rotation speed.

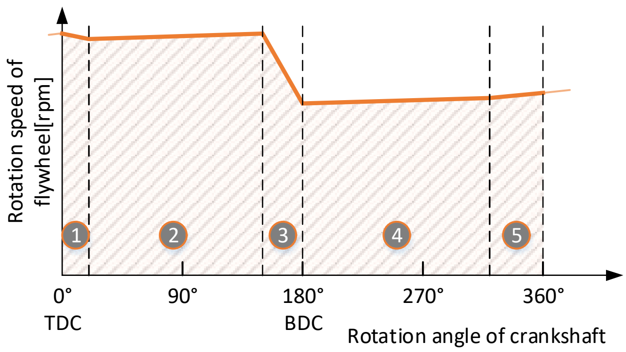

Figure4. Rotation speed of countershaft (significant phase of stroke)

The working stroke of the crank press is divided into several phases:

Nominal accumulated energy is reached before phase 1.

1 Clutch is turned on. Part of the energy of the drive is transmitted to the moving crank shaft. Part of the energy is wasted by the clutch slipping.

2 Ram moves down in this phase, but the forming operation does not happen. Energy which is wasted by the clutch turning on is re-charged during this phase.

3 Forming operation happens in this phase. The maximum energy which can be used for forming is the energy which causes decreasing rotation speed of flywheel by about 30 %. (It causes decreasing rotation speed of all parts of drive by about 30%). A rotation speed decrease of about 30% corresponds with an accumulated energy decrease of about 50%.

4 After reaching bottom dead centre the ram goes up to the top dead centre. The energy which is wasted in the forming operation is charged during this phase.

5 In this phase the clutch is turned off and the countershaft is disconnected by the crankshaft. Then the crank shaft is stopped by the brake. Subsequently, the crankshaft is braked and stopped altogether using the brake, and this energy is wasted.

After 5 In this phase the energy of the flywheel used for the stroke is charged by the electric motor after disconnecting the crank shaft. This phase is not shown in the graph. After reaching nominal accumulated energy, the process is repeated.

4 CASE STUDY

[Moravec 2016, Siemens 2012]

A crank press with nominal force 25MN was analysed with the aim of obtaining time data about the operation of the machine. This data will be used in the new design of a drive with a higher number of strokes per minute. The parameters of this machine are given in Table 2.

For the sake of simplicity, the passive effects of the driveare not included. The influence of the variable transmission of the crank mechanism is also ignored (the kinetic energy of the ram is low compared to the energy of the rotating parts).

In this solution, the electric motor provides energy during the whole stroke. The electric motor can be overloaded by 2.5 times. The results in all the phases are as follows

Table 1. Specific values in various stages of stroke of initial design condition

Phase	Rotation angle	Kinetic energy - rotational [kJ]	Rotation speed of countershaft [rpm]	Rotation speed of crankshaft [rpm]	Time [s]
Before 1	0°	1 763	271	0	0
1	20°	1 725	266	69	0,096
2	150°	1 768	270	70	0,407
3	180°	895	190	50	0,492
4	320°	965	200	52	0,972
5	360°	740	205	0	1,247
After 5			271		2,855

The results reveal that the number of usable strokes of the machine is 21 per minute.

4.1 *Possible modifications to the existing drive*

The following conditions were selected for making modifications:

- Increase the number of work strokes (leads to better efficiency of machine with automatic handling of workpieces)
- Rotation speed of countershaft is slower than 100 revolutions per minute during continuous operation of machine. (If rotation speed of countershaft is higher than 100 revolutions per minute we cannot use automatic handling)
- Maintain the amount of energy which is used for forming (storing a lot of energy which is not used for forming is wasteful). The maximum limit of rotation speed was decreased by about 30% to determine the amount of energy which is used for forming.
- All losses of drive are ignored.

4.2 Solution

The results for increasing the number of work strokes of the machine are:

- One way to increase the work stroke number is to change the electric motor and modify the flywheel. Energy which is accumulated in the flywheel is highly dependent on the flywheel speed. This is why increasing the speed of the electric motor and increasing the speed of the flywheel is the best way to improve the efficiency of the machine. When the electric motor speed increases, the moment of inertia decreases, assuming the same accumulated energy. A lower moment of inertia is connected with lower weight, so we save material. The next fact is that an electric motor with higher speed is cheaper, so we also save money.

4.3 Variant 1

The first variant involved changing the electric motor speed from 738 revolutions per minute to 988 revolutions per minute. This caused a decrease of the diameters of the drive pulley and the flywheel, and an increase of the countershaft speed. The gear ratio between the countershaft and the crank shaft was changed to avoid the crankshaft spinning too fast.

Increasing the electric motor speed led to increasing the countershaft speed by about 78% and to increasing the crankshaft speed by about 37%. This modification led to a considerable decrease of the weight of the flywheel, assuming the same accumulated energy. The new flywheel is about 2 300 kg lighter than the existing one.

The design for the new machine must have the same energy requirements for forming as the existing machine (approx. 880 kJ). This was the main requirement of the design. More energy is used in the new machine. This is compensated by a lower reduction of rotation speed – by only 22%.

Nominal torque of the crank shaft was increased because the gear ratio between the countershaft and the crankshaft was changed.

Variant 1 has a higher number of working strokes per minute (see Table 2). The number of working strokes per minute was increased from 28 to 35, and the new machine is about 4 600 kg lighter.

4.4 Variant 2

In this variant the electric motor was changed. The new motor has 1 400 revolutions per minute. The gear ratio between the motor and the countershaft was also changed. The gear ratio between the countershaft and the crankshaft is the same as in the existing machine. This allows the existing construction of the press frame to be used. The countershaft speed and crankshaft speed are slightly increased compared to Variant 1.

Because the electric motor speed was increased, the countershaft speed and crankshaft were increased too. The countershaft speed is increased by about 11%, and the crankshaft speed by about 10 %. This is better than Variant 1 because the higher speeds of the countershaft and crankshaft lead to higher demands on the press frame construction. The countershaft assembly is about 620 kg lighter than the existing one.

More energy is used in the machine drive than in the existing design. This higher amount was compensated by a lower decrease of rotation speed. Rotation speed decreases by only 28%.

Variant 2 has a higher number of working strokes per minute. The number of work strokes increases from 28 to 43 work strokes per minute (see Tab. 2), and the new machine is about 620 kg lighter.

Table 2. Parameters of existing drive and parameters of proposed drive

		Existing proposal	Variant 1	Variant 2
Electric motor para-meters	Designation of electric motor SIEMENS	1LG4 318-8AB	1LG4318-6AA	1LG4316-4AA
	Performance of electric motor [kW]	132	160	160
	Rotation speed of electric motor [rpm]	738	988	1,486
	Efficiency of electric motor [-]	94.2	93.8	93.8
Belt drive para-meters	Diameter of driving pulley of electric motor [mm]	530	530	300
	Diameter of driving pulley of flywheel	1,400	1,100	1,200 and 1,400
	Gear ratio [-]	2.71	2.07	4.67
Gearing parameters	Gear ratio [-]	3.86	5	3.86
Rotation speed of shafts	Counter-shaft speed [rpm]	270	481	300
	Crankshaft speed [rpm] – continuous operation	70	96	77.5
Decrease of rotation speed of flywheel [%]		30	22	28
Energy which is used for forming [kJ]		880	878	884
Number of work strokes		28	35	43

5 CONCLUSION

The goals of the task were met as follows:

1. Variant 1 has about 25% more work strokes, and Variant 2 has about 52% more work strokes. Performance of the electric motor increased from 132 kW to 160 kW, an increase of about 21%.

2. The flywheel of Variant 1 is about 4 600 kg lighter than the existing one (saving 47%). The flywheel of Variant 2 is about 620 kg lighter than the existing one (saving 6%).

3. Further benefits are decreased electric motor weight and motor price (see Tab. 3). The price of the motor decreases as its speed increases.

Table 3. Price of electric motor

Electric motor SIEMENS	Performance [kW]	Rotation speed [1/min]	Weight [kg]	Price without VAT [CZK]
1LG4 318-8AB	132	738	1 100	287 534
1LG4 318-6AA	160	988	1 180	276 896
1LG4 316-4AA	160	1 486	955	186 640

The authors were able to design a crank press drive which is able to work faster. The productivity of the whole forging line was increased by about 25% thanks to increases in the frequency of the working strokes of the crank press.

The question remains how the change of the drive affects the energy efficiency of the mechanical part. Energy efficiency is usually analysed through energy balance, which is not calculated. Despite this assumption, we can make some favourable conclusions. Generally, the efficiency of an electric motor increases with the number of poles. This assumption is not reflected in this case because it is only true for motors with lower performance.

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