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The analysis of the impact of technological processes of hot forging on the dynamics of the crank press

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Abstract. The article deals with a dynamic model of a crank hot stamping press, which allows evaluating the effect of elastic torsional, bending deformations and tensile strains of compression of its elements, taking into account gaps in the kinematic pairs, depending on the technological process implemented on this press. Given that there are always several options to realize a technological process of hot volume forging, designed for a specific part, the proposed method allows you to choose the best option in terms of the working conditions of the press.

1. Introduction

In the foreseeable future hot volume forging (HVF) using crank hot stamping presses (CHSP) will remain one of the main manufacturing methods high performance forgings. The key element of their cost is metal and hardware investments. The classical method of making forgings of a given size is to tighten the flash bridge conditions to increase its width and to reduce the height. At the same time, the stamping force increases, and the operating conditions of the equipment deteriorate, especially due to the oscillatory (dynamic) processes in the system combining shafts, a connecting rod, a slide and a press frame [1, 2, 3].

The obvious means of improving reliability and durability of the press is to create new technological schemes of HVF which make it possible to minimize the dynamic processes in the CHSP by changing the technological loads graphs and their magnitude [5, 6].

2. A mathematical model

A mathematical model of the press is a system of ordinary, nonlinear, piecewise continuous differential equations of the second order, describing the motion of the mass system, interconnected by kinematic and elastic-dissipative bonds of a dynamic model (figure 1). In developing a dynamic model of a GHSP maximum loads were assumed to occur at the end of the working stroke of the slider. In this case the rotating component of the force acting from the slider to the main shaft of the press is minimal. During this time interval, the press elements (a frame, a connecting rod and a slider) are mainly under tensile-compression deformation, and the main shaft is working for bending. For the rest of the time, the main shaft loading circuit is torsion and bending.

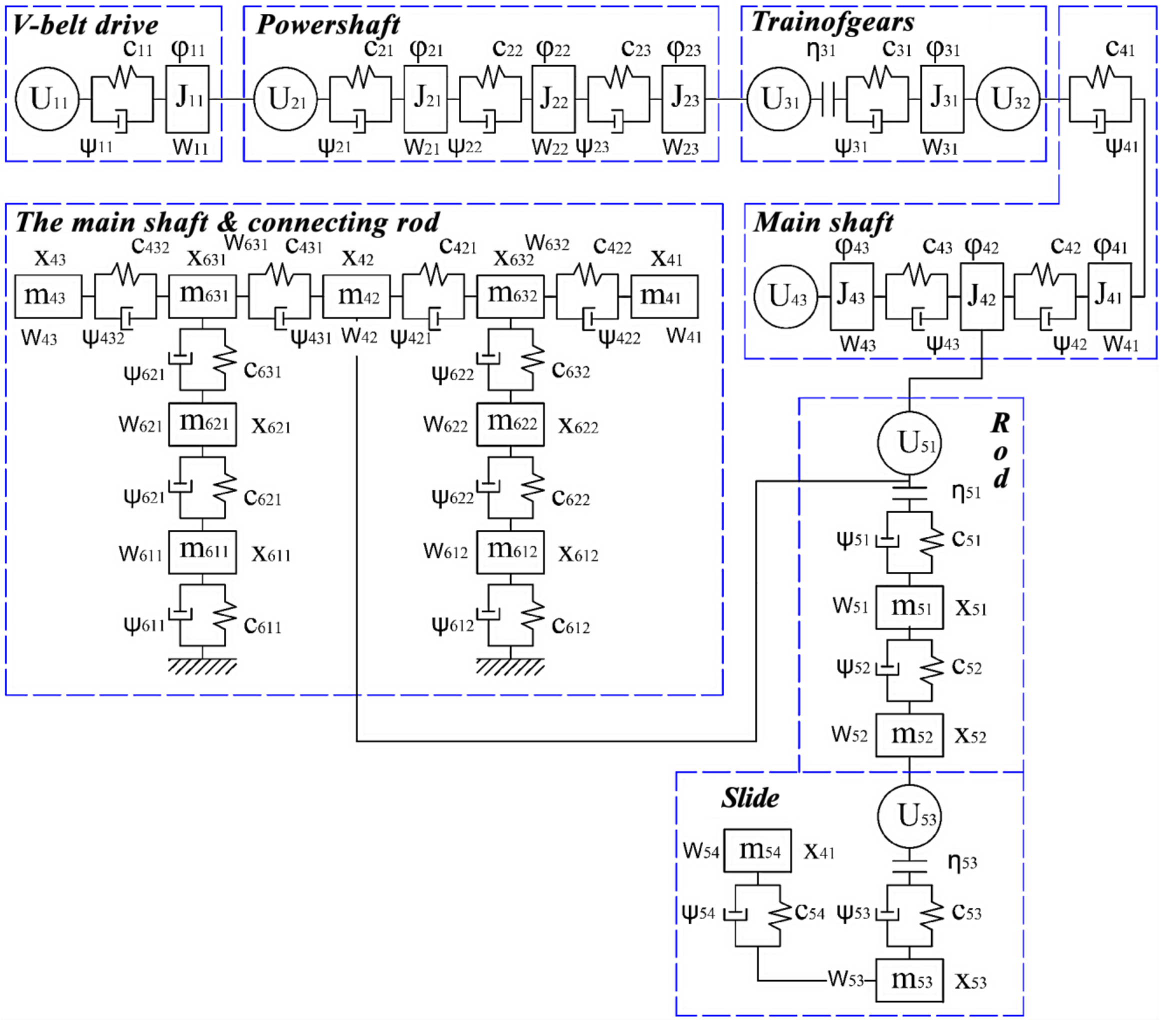

Figure 1. A dynamic model of a crank hot-stamping press.
J_{ij} – moment of inertia, m_{ij} – mass, C_{ij} – stiffness, ψ_{ij} – coefficient of dissipation, η_{ij} – gap, U_{ij} – function of position, W_{ij} – external load of the mass j of the i-th mechanism.

The method of constructing a mathematical model is based on the application of the Lagrange equation of the second kind, and, for example, the equations of masses motion for a crank-slider mechanism (figure 1) can be written as:

$$\begin{cases} m_{51}\ddot{x}_{51} = -c_{51}(x_{51} - U_{51}) - b_{51}(\dot{x}_{51} - U'_{51}\cdot\dot{\varphi}_{42}) + \Omega_{56} \\ \qquad + c_{52}(x_{52} - x_{51}) - b_{52}(\dot{x}_{52} - \dot{x}_{51}) + W_{51} \\ m_{52}\ddot{x}_{52} = -c_{52}(x_{52} - x_{51}) - b_{52}(\dot{x}_{51} - \dot{x}_{51}) + \\ \qquad + c_{53}(x_{53} - U_{53}) - b_{53}(\dot{x}_{53} - U'_{53}\cdot\dot{x}_{52}) + W_{52} \\ m_{53}\ddot{x}_{53} = -c_{53}(x_{53} - U_{53}) - b_{53}(\dot{x}_{53} - U'_{53}\cdot\dot{x}_{52}) + \\ \qquad + c_{54}(x_{54} - x_{53}) - b_{54}(\dot{x}_{54} - \dot{x}_{53}) + W_{53} \\ m_{54}\ddot{x}_{54} = -c_{54}(x_{54} - x_{53}) - b_{54}(\dot{x}_{54} - \dot{x}_{53}) + W_{54} \end{cases}, \quad (1)$$

$$\begin{aligned} \Omega_{45} &= c_{51}(x_{51} - U_{51}) + b_{51}(\dot{x}_{51} - U'_{51}\cdot\dot{\varphi}_{42}) \\ \Omega_{56} &= c_{51}(x_{42} - x_{51} + U_{51}) + b_{51}(\dot{x}_{42} - \dot{x}_{51} + U'_{51}\cdot\dot{\varphi}_{42}) \end{aligned}, \quad (2)$$

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$$
\begin{aligned}
&U_{51} = R \cdot (1 - \cos(\varphi_{42}) + L - \sqrt{L^2 - 2R \cdot \sin(\varphi_{42})}, \\
&U'_{51} = R \cdot \sin(\varphi_{42}) \cdot \left(1 + \frac{R}{\sqrt{L^2 - 2R \cdot \sin(\varphi_{42})}} \right), \\
&U_{53} = x_{52}, \; U'_{53} = 1.
\end{aligned} \tag{3}
$$

In equations (1 – 3) $x_{5n}, \dot{x}_{5n}, \ddot{x}_{5n}$ are linear displacements, velocities and accelerations of masses of the crank mechanism (n = 1 ... 4); m_{5n}, c_{5n}, b_{5n} are masses and elastic-dissipative characteristics of the model; W_{5n} are external loads: friction forces, a balancer of the slider, a processing load; Ω_{45} is the impact of the connecting rod of the press on its main shaft; Ω_{56} is the impact of the system "frame – main shaft" on the connecting rod; R is the radius and L is the length of the connecting rod, respectively.

To assess the level of dynamic processes in a crank-slider mechanism of the press, we will use the criteria (4):

$$
K_s = \frac{P_{cp}}{Ps_{cp}}, \quad K_m = \frac{P_{\max}}{Ps_{\max}}, \tag{4}
$$

where P_{cp}, P_{Scp}, P_{max} and P_{Smax} are an average dynamic, an average static, the maximum absolute value of the dynamic and static loads in the investigated element of the mechanism, calculated for the time interval $[T_1, T_2]$ respectively. The coefficient K_m determines a relative level of the maximum load in the investigated press mechanism and is an indicator of strength. The value of K_S depends on the amplitude, the frequency, the rate of vibration damping and is an indicator that determines wear and a fatigue failure. The values of an average and the maximum dynamic loads, for example, in the press rod can be found from the solution to its equations of motion according to the dependencies (5):

$$
P_{cp} = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \left| c_{51}(x_{51} - U_{51}) \right| \cdot dt, \;\; P_{\max} = \max \left| c_{51}(x_{51} - U_{51}) \right|_{T_1}^{T_2}. \tag{5}
$$

One of the modern trends of designing CHSP processes is the formation of pre-transition technological projections that on reducing the forging efforts allow a forging with minimal stamping radii to be made, and machining allowances to be reduced (figure 2).

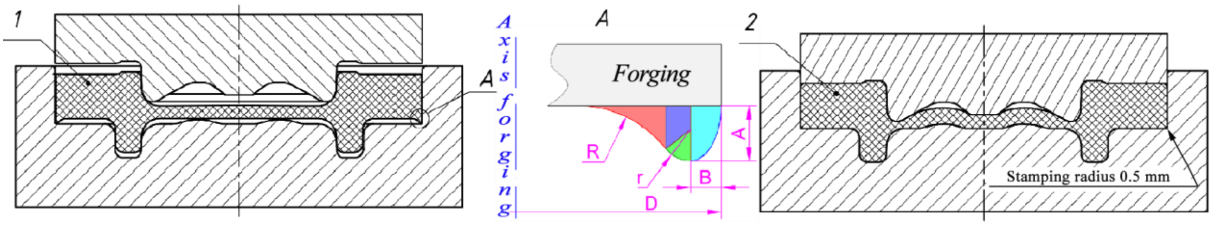

Figure 2. Stamping round forgings (the final transition):
1 – half-finished product, formed during the preliminary forming transition, 2 – finished forging.

The mathematical model (6, 7), setting the configuration of the projection (figure 2) at $y(x)$ is:

$$y=\begin{cases}-\frac{A}{B}\cdot\sqrt{\left|(x-0.5\cdot D+B)^2-B^2\right|}, & 0\le x-0.5\cdot D+B\le B\\ r-A-\sqrt{\left|(x-0.5\cdot D+B)^2-r^2\right|}, & -r\cdot\sin\alpha\le x-0.5\cdot D+B\le 0\\ -R+\sqrt{\left|(x+(r+R)\cdot\sin\alpha-0.5\cdot D+B)^2-R^2\right|}, & \begin{cases}x-0.5\cdot D+B\le -r\cdot\sin\alpha\\ x-0.5\cdot D+B\ge -(r+R)\cdot\sin\alpha\end{cases}\end{cases}\qquad(6)$$

In equations (6) the angle in radians is $\alpha=\arccos\left(\frac{R-A+r}{r+R}\right)$.

$$\begin{cases}\overline{\alpha}=90-\frac{180\cdot\alpha}{\pi};\quad 20°\le\overline{\alpha}<90°\\ 0.6\le\frac{4\cdot A^2}{\pi\cdot A\cdot B+2\cdot(r^2-R^2)\cdot\alpha+4\cdot(A-r)\cdot(r+R)\cdot\sin\alpha+(r+R)^2\cdot\sin 2\alpha}\le 1.2\end{cases}\qquad(7)$$

Expression (7) determines the conditions of defect-free stamping at the final transition of a semi-finished product with a projection obtained at the preliminary transition.

3. Results and discussion

In the context of the influence of geometric parameters of a tool for hot forging extruded round in plan forgings on the dynamics of a crank press, the following tasks were solved:

- The search for the parameter values *A*, *B*, *R* and *r* (figure 2), allowing to minimize the maximum static force P_{Smax} at the final transition when forming a stamping radius not exceeding 0.5 mm on the outer side of a forging.
- The calculation of the criteria for K_m, K_S, P_m, and P_s at the obtained values *A*, *B*, *R*, and *r*.
- The study of the impact of changes of the values *A* and *R* on the criteria K_m and K_S. Here, taking into account the results of problem №1, $B = 0.5{\cdot}A$, $r = B$ are adopted.

To calculate dynamic characteristics of a press, special software [7] was used. This software is based on dynamic (figure 1) and mathematical (1) – (5) models, as well as the software of the company QuantorForm Ltd. – QForm 8. Its aim is to simulate the HVF process and calculate technological loads [3, 5, 8, 9].

The object of study is forging, manufactured on the CHSP K8542. The press capacity is 16 MN to fit the technological scheme presented in figure 2.

Problem №1 – the solution by the method of coordinate descent with limits (7). The result is P_{Smax} = 10.78 MN, P_{Scp} =2.18 MN at A = 3.0 mm; B = 1.5 mm; R = 3.5 mm; r = 1.5 mm.

Problem №2. The result is K_m = 1.05, K_S = 1.27, P_m = 11.32 MN and P_s = 2.78 MN.

Problem №3. The variation range of the parameters *A* and *R* is ≈ 10%. The results are outlined in table 1.

Table 1. Values of the criteria K_m/K_S at different values of the parameters *A* and *R*.

		Parameter A, mm						
		2.4	**2.6**	**2.8**	**3.0**	**3.2**	**3.4**	**3.6**
Parameter R, mm	**3.0**	1.06/1.27	1.06/1.28	1.05/1.26	1.06/1.26	1.07/1.27	1.06/1.27	1.04/1.27
	3.2	1.05/1.28	1.06/1.28	1.05/1.27	**1.05/1.26**	1.06/1.27	1.06/1.27	1.04/1.28
	3.4	1.05/1.28	1.04/1.29	1.04/1.28	1.06/1.26	**1.05/1.26**	1.06/1.28	1.06/1.29
	3.5	1.05/1.29	1.04/1.30	1.04/1.28	**1.05/1.27**	1.06/1.28	1.06/1.29	1.07/1.29
	3.6	1.05/1.29	1.05/1.30	1.04/1.28	1.05/1.28	1.06/1.28	1.05/1.29	1.07/1.29
	3.8	1.05/1.30	1.05/1.31	1.04/1.29	1.06/1.30	1.06/1.29	1.06/1.30	1.08/1.30
	4.0	1.04/1.30	1.06/1.31	1.04/1.29	1.06/1.30	1.05/1.29	1.06/1.31	1.08/1.32
	4.2	1.04/1.31	1.06/1.32	1.04/1.30	1.06/1.31	1.06/1.30	1.07/1.32	1.09/1.34

Table 1 shows different zones of values of the parameters *A* and *R*. Yellow ink (the right top corner) marks the appearance of stamping defects; brown ink (the bottom left corner) marks the stamping radius exceeding the established value (0.5 mm); green ink marks close to optimum values of varied parameters.

4. Conclusion

The article presents a mathematical model of plastic deformation of a forging made on a crank hot stamping press. It allows estimating the level of dynamic loads in the press elements, depending on geometric parameters of the tool used to form the forging. The efficiency of this model is checked by hot forging extruded round in plan forgings on crank presses. As a result close to optimum values of the tool geometric parameters were found.

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