COMBINED DOUBLE CRANK WEDGING DRIVE MECHANISMS OF THE PRESS PLATE USED IN DIE-CUTTING PRESS: SYNTHESIS, KINEMATIC AND FUNCTIONAL

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ABSTRACT: The production of cardboard packaging begins with the die-cutting of sweeps on special presses equipped with wedging lever mechanisms for driving the press plate, ensuring the forced interaction of tools of a flat die-cutting stamp with cardboard cuttings. It set a goal to provide the needed duration of contact of the technological tools of the die-cutting stamp for creasing the bending lines and forming relief images. It is offered to use additionally driven cranks in the wedging drive mechanisms of the press plate. There are examined schemes of combined wedging drive mechanisms of the press plate: existing mechanism, double-crank with upper and lower initial positions of the driven crank. Their relative geometrical parameters were taken to synthesize and calculate the mechanisms under study. Based on the results of analytical studies, the perspective of their application was outlined.

KEYWORDS: die-cutting press, wedging mechanism, driven crank, press plate, invariant.

1 INTRODUCTION

Among the important trends in the development of packaging, the recycling of materials holds a valuable place, which confirms their sustainability. Today, manufacturers of packaging materials try to use packaging materials suitable for 100% recycling (Kryvoshey V. M., 2022). These materials include paper and cardboard, which are recognized as important to the renewable packaging market sector.

Paper and cardboard packaging production is preceded by die-cutting of their sweeps on special presses, which are the components of die-cutting machines. The presses are equipped with wedging lever mechanisms that provide the press plate with vertical movement to create conditions for the free movement of carriages with cardboard cuttings through the working area (first phase) and to ensure the force interaction of the tools of the flat die-cutting stamp with the material (second phase) (Rehei I. I., 2011). The results of the die-cutting of cardboard cuttings largely depend on the implementation of the second phase.

It is suggested to implement additional adjustments of the press plate parameters in the interaction of the stamp tools with the cardboard to ensure high-quality die-cutting of cardboard sweeps.

The reason for the need for such correction is primarily related to the peculiarities of the design of the flat die-cutting stamp, which is designed to perform two primary operations: dividing the cardboard blank (CB) (Fig. 1a) with cutting rules 1 and creasing with rules 2 (Fig. 1b) and cold relief stamping of the cut form 3 (Fig. 1c) of separate fragments of the cutting, which are not related to its division.

Figure 1. Schemes of the die-cutting stamp tools interaction with a cardboard cutting: cutting (a), creasing of bending lines (b), relief stamping (c)
Different types of operations require the specific action of die-cutting stamp tools of a different design: the division of cardboard by cutting is a short-term procedure, and ensuring the performance of high-quality creasing and relief cold stamping of material is possible under the condition of durable contact of creasing rules and metal cut forms with cardboard.

Extending the duration of contact of the technological tools of the die-cutting stamp, involved in forming compacted creasing lines and relief images, is intended to be solved by using an additional driven crank in the design of the wedging drive mechanisms of the press plate.

The analysis of the existing drive mechanisms of press plate in modern die-cutting equipment showed that they overcome significant technological loads at the end of the working movement during the contact of the stamp tools with the cardboard cutting (Khvedchyn Y. Y. & Zelenyi V. V., 2014).

The work (Vlakh V. V. & Pasika V. R., 2016) suggested a methodology for optimizing the operation of the main shaft of the die-cutting press. Its application is intended to increase the productivity of die-cutting equipment, provided that energy consumption is reduced. Analytical dependences for the synthesis of mechanisms are presented. To avoid the oscillating movement of the press plate of the die-cutting press, the authors suggested using a double-crank four-link rocker mechanism, which contributes to improving the quality of the production of sweats. However, using additional mechanisms complicates the design and adjustment of the die-cutting press.

In the work (Pasika V. R. & Vlakh V. V., 2016), the authors investigated a wedging mechanism with a variable swing angle of a double crank to eliminate the shortcomings associated with the oscillating movement of the press plate. It is suggested to minimize it by reducing the swing angle of the two-armed drive crank. This approach does not solve the problem of the operation of the die-cutting press in full, but it minimizes operational issues.

The work (Lin W. & Zhou C. & Huang W. 2015) presents the research results on die-cutting presses with a double cam mechanism for improving the kinematic characteristics of the press plate. However, the suggested design is characterized by the complexity of manufacturing drive cams with two contact profiles due to the high requirement for their accuracy. A new design of wedging cam drive mechanisms for driving the lower press plate of a die-cutting press is known (Shakhbazov Y. O. & Cheterbukh O. Y. & Shyrokov V. V. & Palamar O. O., 2020), but despite a somewhat simplified design, the mechanism remains complex in setting up and operation.

The authors in the work (Behen P. I. & Radikhovskiy I. A. & Mlynko O. I., 2020) suggested a new design of the drive of the press plate of the die-cutting press using a screw-nut transmission, and in work (Rehei І. I. & Knysh O. B. & Behen P. I. & Radikhovsky I. A & Mlynko O. I., 2020) they estimated the components of the consumed kinetic power of the drive. Given their technical capabilities, it is worth outlining the direction of the application of such presses.

The purpose of this work is to synthesize the combined double-crank wedging drive mechanisms of the press plate drive in die-cutting presses, to perform a comparative analysis of kinematic parameters and technical functioning with the existing mechanism, to justify the possibilities of adjusting the parameters of the suggested mechanisms to ensure the high-quality die-cutting of cardboard sweeps.

2 MECHANISMS, MATERIALS, AND METHODS

The existing and suggested combined wedging drive mechanisms of the press plate in the die-cutting press contain the support plate I (Fig. 2, 3) with a flat stamp II, press plate III, the driving circuit (crank 1.1, beam 1.2, rocker 1.3) and the driven circuit (beam 2.1). The suggested mechanism differs from the existing one using a second crank in the driven circuit. The new construction of the mechanism was implemented by attaching to the four-link, which includes the driving crank 1.1, and the gear wheel 1.4 (Fig. 3), attached to the hinged connection of the beam 1.2 with the rocker 1.3. The gear wheel 1.4, in the rocking motion of the rocker 1.3, rolls over the stationary gear sector 1.5. The second driven crank 1.6 of the drive of the press plate III, which is hingedly connected to the driven beam 2.1, is rigidly connected to the gear wheel shaft 1.4.

This configuration of the existing combined wedging mechanism with a driven crank 1.6 enables the correction of the cardboard die-cutting process during the final phase of the vertical movement of press plate III.
In the studies, the following designations of the combined wedging mechanisms of the left circuit of the press plate drive were adopted:

- the driven circuit (four-link) in the existing mechanism: O1O2 – base-to-base distance (Fig. 4a); O1A – driving crank (A1 corresponds to its initial position, and A2 – to its final position; similar designations apply to other links of the mechanism (except the base-to-base distance); AB – beam; O2B – rocker;
- driven circuit (Crank-and-slider mechanism) in the existing mechanism: O2B – crank (Fig. 4a); BD – beam;
- driven circuit in double crank mechanism: BC – driven crank (Fig. 4b, Fig. 4c); CD – beam.
Complementing the existing combined wedging drive mechanism of the press plate with the driven crank DC is intended to implement additional adjustments to the parameters of the press plate to ensure the high-quality performance of the die-cutting of cardboard sweeps. The need for such correction is primarily related to the design of the flat die-cutting stamp, designed to perform two primary operations: division (destruction) of cardboard and creasing and cold relief stamping unrelated to its division.

Different types of operations require the specific action of tools of the die-cutting stamp, which are different in design: the division of cardboard by cutting is short-term, and ensuring the performance of high-quality creasing and relief cold stamping of the material is possible under the condition of relatively durable contact of creasing rules and metal cut forms with cardboard. Therefore, the issue of prolonging the contact duration of the die-cutting stamp's technological tools, involved in forming compacted creasing lines and relief images, is intended to be solved by using an additional crank in the design of the driven circuit of the wedging mechanism.

For the synthesis and calculation of the studied mechanisms, the following relative parameters are taken as input: \( \lambda_H = 3.4 \) – the height of the mechanism; \( \lambda_W = 5 \) – its width; \( \lambda_S = 1 \) – the movement of slider D; \( \lambda_e = 0.2 \) – the length of the driven crank (BC). Analytical dependences for calculating other parameters are given in the table.

### Table 1: Analytical dependences for synthesis and calculations of parameters for the combined wedging mechanisms of various types

<table>
<thead>
<tr>
<th>Order No.</th>
<th>Types of welding mechanism</th>
<th>Parameter</th>
<th>Analytical dependences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>The relative height of the mechanism in the lowest position</td>
<td>( \lambda_0 = 2\lambda_H - \lambda_S ).</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Relative base-to-base size</td>
<td>( \lambda_1 = \sqrt{\lambda_H^2 + \lambda_W^2} ).</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>The angle of inclination of the base-to-base distance to the horizontal axis</td>
<td>( \gamma_{01} = \arctan(\frac{\lambda_H}{\lambda_W}) ).</td>
</tr>
<tr>
<td>4</td>
<td>( \angle O1O2B2 ) (uppermost position of the mechanism)</td>
<td>( \gamma_{max} = \arcsin\left(\frac{\lambda_W}{\lambda_1}\right) - \gamma_0 ).</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>The relative dimensions of the beam and rocker of the driven circuit</td>
<td>( \lambda_3 = 2\lambda_H \frac{\sin(\gamma_0)}{\sin(\pi - 2\gamma_0)} ).</td>
</tr>
<tr>
<td>6</td>
<td>Existing</td>
<td>The angle of inclination of the rocker of the driving circuit to the vertical axis in the lowest position of the mechanism</td>
<td>( \gamma_{02} = \arccos\left(\frac{\lambda_0^2}{2\lambda_3 \cdot \lambda_0}\right) ).</td>
</tr>
<tr>
<td>7</td>
<td>( \angle O1O2B1 ) (the lowest position of the mechanism)</td>
<td>( \gamma_{min} = \arcsin\left(\frac{\lambda_W}{\lambda_1}\right) - \gamma_{02} ).</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>The swing angle of the rocker of the driven circuit</td>
<td>( \gamma_\Sigma = \gamma_{02} - \gamma_0 ).</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>The relative size of the beam of the driving circuit</td>
<td>( \lambda_2 = \frac{\lambda_{01B2} + \lambda_{01B1}}{2} ).</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>The relative size of the crank of the driving circuit</td>
<td>( \lambda_R = \frac{\lambda_{01B2} - \lambda_{01B1}}{2} ).</td>
</tr>
</tbody>
</table>
According to the results of analytical calculations, the received values invariants of moving the press plate in the existing wedging mechanism and the suggested two-crank ones with the lower and upper initial positions of the driven crank were obtained.

The research synthesized the existing wedging mechanism and the suggested double cranks, in which the relative movement of the press plate $S_i = 1$. The use of the wedging mechanism with the lower initial position of the driven crank is accompanied by an expansion of the shape of the curve $S_i = f (\varphi)$ at the end of the working stroke of the press plate (Fig. 5). Its narrowing is observed for the mechanism with the upper initial position of the driven crank.

The results of analytical studies made it possible to carry out a comparative analysis of the duration of the interaction of the die-cutting tool with the cardboard cutting in the suggested double-crank wedging mechanisms and the existing one. The relative parameter of the cardboard thickness $\lambda \Delta$, widely used in producing cardboard sweeps, is introduced for calculations. It was established that the interaction of the tools of the die-cutting stamp with the cardboard cutting in the existing wedging drive mechanism of the press plate takes place during the angle of rotation $\Delta \varphi_1 = 20^\circ$ (Fig. 6) of the driving crank.

In the suggested double crank mechanisms with the lower and upper initial positions of the driven crank, the mentioned interaction takes place during, respectively, $\Delta \varphi_2 = 28^\circ$ and $\Delta \varphi_3 = 16.5^\circ$.

Thus, using a double crank wedging mechanism with the lower initial position of the driven crank extends the duration of the interaction of the die-cutting tools of the stamp with the cardboard cutting by 1.4 times relative to the duration in the existing mechanism. Moreover, using a similar mechanism with the upper initial position of the addition crank reduces it by 1.21 times.
Fig. 6 Graphs of dependences on the angle of rotation of the driving crank of moving invariants of the he press plate in the contact area of the die-cutting stamp with the cardboard in wedging mechanisms: existing (1), suggested double-crank ones with the lower (2) and upper (3) initial positions of the driven crank

3 CAD/CAE MODELLING

The results of analytical calculations indicate that the combined double crank mechanism for driving the pressure plate with the lower position of the driven crank has positive characteristics due to the prolonged presence of the pressure plate in the technological operation zone. To study such a mechanism in absolute values (rather than relative), during the research, modeling of the proposed mechanism was carried out in the SolidWorks automated design system to obtain a simulation of its operation and get the results of the kinematic analysis.

For the parametric synthesis of the geometric parameters of the mechanism and the construction of a 3D model, the input parameters of the mechanism were accepted as follows: W = 250 mm - width of the mechanism; H = 170 mm - the height of the mechanism; S = 50 mm - displacement of the pressure plate; BC = 10 mm - the size of the driven crank; n = 60 rev/min - rotational speed of the main shaft (complete cycle of the mechanism's operation per 1 second). Such parameters were determined for a stamping press with a pressure plate of SP76 format of 760x560 mm. The calculations of the main geometric parameters were carried out based on the derived analytical dependencies (Table 1).

As a result of the calculation, the size of the rocker arm O2B (see Fig. 4) is determined to be 170.6 mm, the size of the connecting rod CD is 160.6 mm, the length of the connecting rod AB is 208.3 mm, and the size of the main crankshaft O1A is 26.7 mm. Based on these values, a 3D model is constructed.

Figure 7 shows the mechanism of the press drive, where FL is the stationary, rigidly fixed pressing plate with the die-cutting form, PP is the pressing plate, cardboard is moving through the press between PP and FL, 1 is the driving crank O1A, 2 is the connecting rod AB, 3 is the rocker arm O2B, 4 is the gear fixed on the same shaft as the driven crank BC 6, 5 is the stationary, rigidly fixed toothed sector, along which gear 4 moves and 7 is the driven connecting rod CD. The mechanism was studied using tools of SolidWorks Motion. Based on the constructed 3D model, a simulation of the mechanism's operation was performed, and a kinematic analysis was carried out. The analysis results were obtained in tabular data, based on which graphs of the pressing plate's velocity and acceleration (Fig. 8, 9) as a function of time were constructed.

![Graph of the velocity of the pressing plate over time.](image1.png)

**Fig 8. Graph of the velocity of the pressing plate over time.**

The graph of the change in the speed of the pressure plate shows that the peak speed during the working stroke is 0.20 m/s, while during the idle stroke, it is 0.22 m/s. The graph also shows that when the pressure plate is in the die-cutting zone (in the middle of the cycle), its speed decreases and approaches zero.

![Graph of acceleration of the pressing plate over time.](image2.png)

**Fig 9. Graph of acceleration of the pressing plate over time.**
Fig. 7. 3D model of a combined double-crank mechanism of the pressing plate of a stamping press with the lower initial position of the driven crankshaft.

The mechanism starts moving from its initial position with an acceleration of 0.9 m/s². The peak acceleration values of the pressing plate on the working stroke are 1 m/s² and -1.3 m/s², and on the idle stroke, they are 1.22 m/s² and -1.4 m/s². The curve of the pressing plate acceleration changes in the technological operation of die-cutting is closest to zero, indicating that inertia forces will also have small values at the moment of die-cutting.

4 SUMMARY AND CONCLUSIONS

Die-cutting presses are equipped with wedging lever mechanisms to ensure vertical movement of the press plate to create conditions for free movement of carriages with cardboard cuttings through the working area and force interaction of flat die-cutting stamp with the material. To ensure high-quality die-cutting of cardboard sweeps, it is suggested to implement additional adjustments of the parameters of the press plate in the process of interaction of the stamp tools with the cardboard by using an additional driven crank.

For the synthesis and calculation of the studied mechanisms, the following relative parameters are taken as input: \( \lambda_H = 3.4 \) – the height of the mechanism; \( \lambda_W = 5 \) – its width; \( \lambda_S = 1 \) – the movement of the press plate; \( \lambda_e = 0.2 \) is the length of the driven crank. According to the results of analytical calculations carried out in the Mathcad environment for mathematical calculations, the values of the moving, speed, and acceleration invariants of the press plate in the existing wedging mechanism and the suggested double crank ones with the lower and upper initial positions of the driven crank were obtained.

The use of a double crank wedging mechanism with the lower initial position of the driven crank extends the duration of the interaction of the die-cutting stamp tools with the cardboard cutting by 1.4 times compared to the duration in the existing mechanism, and the use of a similar mechanism with the upper initial positions reduces it by 1.21 times.

The results of the calculations indicate that using the wedging mechanism with the lower initial position of the driven crank will positively impact the die-cutting operation's performance. Therefore, the SolidWorks Motion system carried out a kinematic analysis of the investigated mechanism. The 3D model of the mechanism was created in actual dimensions, its operation was simulated, and
the results of the kinematic analysis were obtained in the form of graphs.

5 REFERENCES


