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Mechanical Crank Presses with a Modified Law of Motion of the Slide. A Patent Study

Romeo CIOARĂ
Transilvania University of Brasov, Romania, cioarar@unitbv.ro
Cristian PISARCIUC
Transilvania University of Brasov, Romania, pisarciuc.c@unitbv.ro

Abstract
The vast majority of mechanical presses are using a crank mechanism for converting the main shaft's uniform rotation into a guided linear reciprocating motion. In many applications, the law of motion ensured by this mechanism is less than adequate, mainly because of the significant variation of slide velocity during the load stroke and the relatively small weighting of the duration of this part of the stroke in relation to the total time of a double stroke. Over time, researchers have conceived more complex conversion mechanisms for mechanical presses, like bar mechanisms that combine crank and four-bat mechanisms in various configurations in order to determine laws of motion of the slide as close as possible to an imposed or assumed optimum. Based on examples from patents and utility models, the paper presents conversion bar mechanisms, double composed and triple composed, designed for mechanical presses in order to ensure the most favourable law of motion of the slide for various applications.

Keywords
mechanical press, law of motion, transformation mechanism

1. Introduction

Presses and mechanical presses in particular, are machine tools used for manufacturing (finished or semi-finished) parts by means of plastic forming procedures, including cutting (blanking, perforating, cropping, slitting, or punching). For optimum performance the various plastic forming operations require a certain value of the mobile tool's mean velocity, thus of the slide, as well as a small as possible variation of the velocity. Both aspects are directly dependent on the slide's law of motion.

Typically, the kinematic structure of mechanical presses is quite simple. Figure 1 present the structural schematic of the main linkage of a mechanical press, where the main motion is a reciprocating translation.

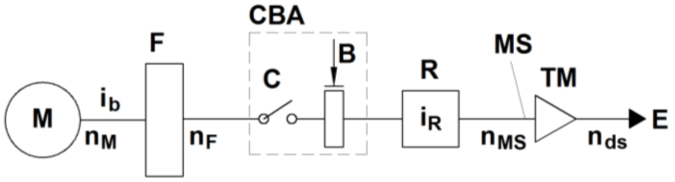


Fig. 1. Structural schematic of the main linkage of a mechanical press [1]
M - actuation motor; F - mechanical energy accumulator (flywheel); CBA - clutch-brake assembly; R - reducing gear; MS – main shaft; TM - motion transformation mechanism; E - final effector element; n_M - speed of the electric actuation motor; n_F - maximum speed of the flywheel; n_{MS} - speed of the main (crank or eccentric) shaft of the press; n_{ds} – number of double stroke per minute / frequency of the main motion (n_{ds} = n_{MS}); i_b - transmission ratio of the belt transmission; i_R - transmission ratio of the press reducing gear

The motor M generate the motion and is the energy source for the main linkage. The motor provides energy continuously in form of rotary motion to flywheel F - a mechanical accumulator of kinetic energy, which is driven at speed n_M. The motion is transmitted to the flywheel typically by using V-belts, by an always reducing transmission ratio i_b (i_b < 1). The nominal speed of the flywheel is $n_F = n_M \cdot i_b$. During the technological cycle - the part of the kinematic cycle when actual pressing occurs - the flywheel releases kinetic energy and reduces its speed implicitly, which is recovered during the no-load phase.

The clutch C is a connecting assembly between the two large sections of the main linkage: a preceding section in permanent motion (motor M, belt transmission and flywheel F) and a subsequent section set into motion following an express command (the mobile part of brake B, reducing gear R, transformation mechanism TM and the effector element E). It is possible for this second part to be in permanent motion, if the machine functions in automatic mode at maximum frequency, or for the rest and motion periods to alternate at constant or variable frequency, if the machines functions in automatic mode at a frequency smaller than the maximum one, namely in singular stroke mode.

Brake B ensures the vigorous and swift stopping of the post-clutch part of the main linkage, with the explicit purpose of stopping the effector element E. Stopping occurs typically shortly before the top dead centre of the slide stroke. In order to prevent an accident or the faulty operation of the machine, brake B needs to be able to operate at any time during the kinematic cycle.

Clutch C and brake B can be distinctive assemblies or can form a more complex assembly, the "clutch-brake assembly" (CBA). The operation of the two subsystems is always correlated.

The reducing gear, in case it exists, ensures a below unity transmission ratio i_R (i_R < 1). The output shaft of the reducing gear is the main shaft (MS) of the machine, its maximum speed being $n_{MS} = n_F \cdot i_R$.

The motion transformation mechanism MT ensures the transformation the main shaft rotation into the linear reciprocating motion with self-return motion of the effector element E. Typically bar mechanisms are used, most frequently a crank - connecting rod - slide mechanism.

The effector element E, the slide of the machine, is the subassembly that carries out the main motion, linear reciprocating and with self-return. The motion frequency of effector element E, n_{ds}, is identical to the speed (motion frequency) of the main shaft: $n_{ds} \equiv n_{MS}$.

The mobile part of the tool is mounted on effector element E and is driven by it in view of performing the specific technological operations.

The law of motion of effector element E (the slide) is determined by the motion type of the transformation mechanism TM and by the motion law of the main shaft of the press. The variation of the main shaft speed is neglected, caused by the diminishing flywheel speed consequently to it releasing part of its kinetic energy to carry out the ongoing pressing operation. Consequently, the main shaft of a mechanical press is considered to be in uniform rotation, thus having a constant speed.

Certain mechanical presses allow the adjustment of the main shaft speed, and thus of the slide motion frequency, but once adjusted, the speed of the main shaft remains constant.

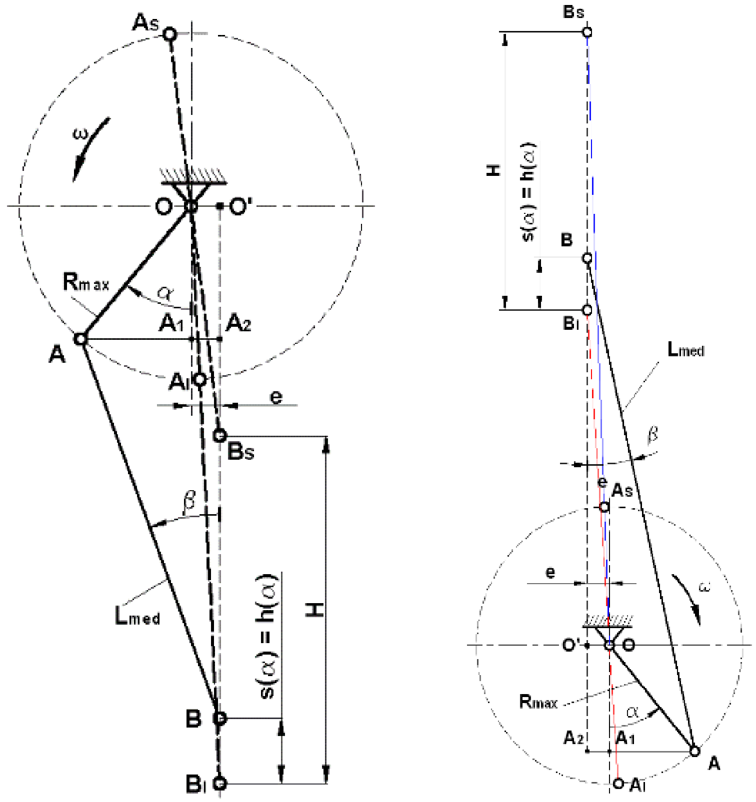
2. The Typical Motion Transformation Mechanism of Crank Presses

For motion transformation, numerous mechanical presses use a crank - connecting rod - slide mechanism of summation type, Figure 2a, consisting of a crank (the pivot or eccentric of the main shaft), a connecting rod and a slide moving along guides fixed to the machine frame. The mechanism is placed at the upper part of the machine and acts upon the slide by pushing during its active stroke. Rather infrequently, a simple crank - connecting rod - slide of differential type is used, Figure 2b, with the same componence as the summation mechanisms, but placed at the inferior part of the press and acts upon the slide by pulling.

The laws of motion of the slide corresponding to the two types of mechanisms are very similar: equations (1) and (2) describe the law of motion of the slide for a summation and a differential type crank mechanism, respectively [1]. Moreover, the deviations of both laws from a (co)sine are quite small, the more so the smaller the values of the connecting rod coefficient are, $\lambda_0 = R_{\max}/L_{\text{med}}$, $\lambda_0 \approx 0.1$, the eccentricity coefficient $k_0 = e/R_{\text{med}}$ being frequently zero or very small. $R_{\max}$ is the maximum crank radius, L_{med} is the average connecting rod length, and α is the current angle of the crank position.

$$s(\alpha) \cong R_{max} \cdot [(1 - cos\alpha)] + \frac{\lambda_0}{4} \cdot (1 - cos2\alpha) + k_0 \cdot \lambda_0 \cdot sin\alpha + \frac{k_0^2 \cdot \lambda_0^2}{2 \cdot (1 - \lambda_0)}. \quad (1)$$

$$s(\alpha) \cong R_{max} \cdot [(1 - cos\alpha)] - \frac{\lambda_0}{4} \cdot (1 - cos2\alpha) - k_0 \cdot \lambda_0 \cdot sin\alpha + \frac{k_0^2 \cdot \lambda_0^2}{2 \cdot (1 - \lambda_0)}. \quad (2)$$



a) b)

Fig. 2. Diagram of principle of the crank mechanism:
a) of summation type; b) of differential type [1]

For a press equipped with a simple summation type crank mechanism, Figure 3 presents the motion law of the slide, its velocity and acceleration.

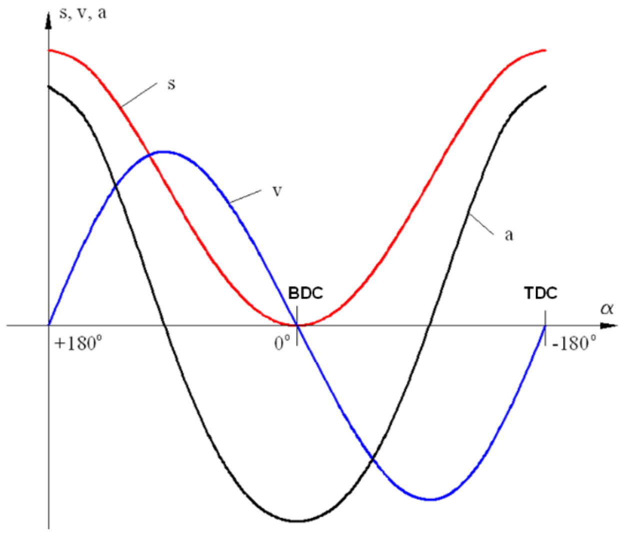


Fig. 3. Graph of the displacement (s), velocity (v) and acceleration (a) equations for a crank press [1].
(BCD - bottom dead center; TCD - top dead center)

The motion law characteristic to the crank mechanism is not the most favourable one for different applications. The modification of the law of motion most often concerns reducing the variation of the slide velocity during the load stroke. A secondary effect is the increase of the slide lowering time - to - slide raising time ratio. This effect can be used to increase the press working frequency, and implicitly its productivity. Causes can be identified when the modification of the law of motion targets increasing the (instantaneous) value of the force available during the load stroke for the same value of the maximum torque available at the main shaft, possibly by minimising the variation of this force for a certain segment of the load stroke.

The motion law of the slide is modified in most cases by "complicating" the transformation mechanism of the main shaft rotation into the guided reciprocating linear motion of the slide, namely by using also other bar mechanisms besides and prior to the crank mechanism, all in sequence, this "series" connected. Most often, such composed transformation mechanisms use one or more bar mechanisms finishing with a crank mechanism.

3. Composed Transformation Mechanisms Used at Mechanical Presses

Mechanical presses, including automatic presses, are using crank shaft mechanism for transforming the rotary motion of the main shaft in a reciprocating translational motion of the slider, Figure 2a. For some small or medium-sized cutting machines, the quadrilateral mechanism is used to transmit the movement from the main shaft to the slide. Some forging machines and automatic presses use the sinus mechanism as a transforming mechanism, in various constructive variants. The mechanisms mentioned are mono-contour and are used when the technological requirements do not require the adjustment of the kinematic parameters except, possibly, the adjustment of the slider stroke length.

Extrusion presses, which require undercarriage and low speeds, are usually equipped with knee mechanisms, double contoured articulated bar mechanisms.

In the construction of the deep drawing mechanical presses, for the drive of the outer slider for retaining the edges of the manufactured part, mechanisms with complex articulated bars are used, most often triple contour, two of them being of a quadrilateral type.

At mechanical presses, the movement law modification of the sliding block of is commonly done by using a sequence of mechanisms with articulated bars. There are patents that propose the use of non-specific transformation mechanisms in mechanical presses. In the literature there are also presented atypical solutions for driving transformation articulated mechanisms, simple or combined. In this case, the drive is made by using a screw-nut mechanism or a linear hydraulic motor. To change the motion law of sliding block there are modes of driving the main shaft of mechanical presses in non-uniform rotation movement. In this case, non-circular gears are used.

3.1. Double composed transformation mechanisms

In literature, constructive solutions of mechanical presses were identified where the transformation mechanism is double composed. This one is consisting of a bar mechanism (that transforms the continuous and uniform rotation of a main shaft into the oscillatory motion of a bar) and a crank mechanism (that transforms that oscillation into the guided linear motion of the slide), or consisting of two successive bar mechanisms.

For the modification of the slide motion law, patent US 2491317 [2] present a relatively simple solution regarding the applied principle and construction, Figure 4.

A bar mechanism transforms the rotation of main shaft 16 into the oscillation of lever bar 32, affixed to crank 27, its oscillation being transformed by a crank mechanism into the guided reciprocating linear motion of slide 14. Depending on the length of bar 19 of the bar mechanisms, during the load stroke lever bar 32 can be actuated by pulling or pushing, which is one of the claims of the patent.

An interesting structure regarding the press transformation mechanism is the object of European patent EP 1504884 [3]. Two bar mechanisms are used, Figure 5, the first one with two fixed axes, consisting of shaft 6 with eccentric 7, bar 9 (part P1-P3) and lever bar 11, the second one having a fixed axis and a translation element, consisting of eccentric 7, bar 9 (the part connecting joints P1 and P2), connecting rod 10 and slide 3. In fact, the complex motion induced upon axis P2 of the joint between bar 9 and connecting rod 10 is deployed.

To be appreciated is the author of patent EP 1504884 concern about ensuring the dynamic equilibrium of the mechanism. The eccentric masses 20 and 21, placed on different shafts of the press reducing gear, contribute to the significant decrease of the first two harmonics of main shaft.

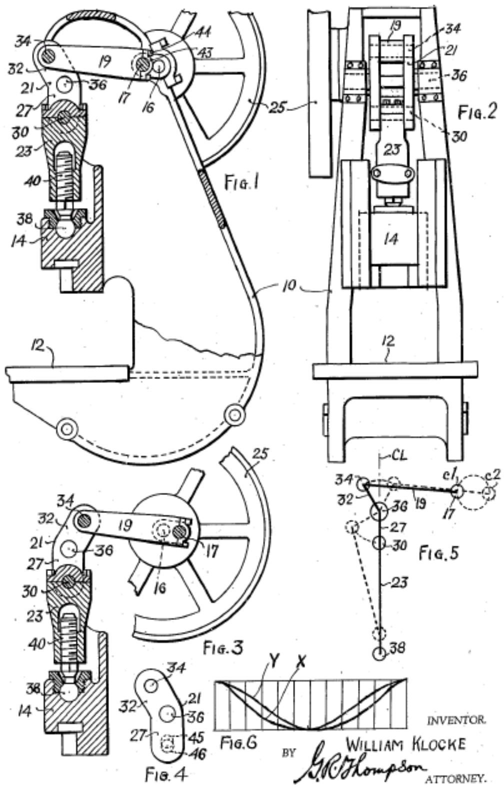


Fig. 4. Mechanical crank press with a composed mechanism (bar mechanism + crank mechanism) designed to modify the motion law of the slide. Solution proposed by patent US 2491317 [2]

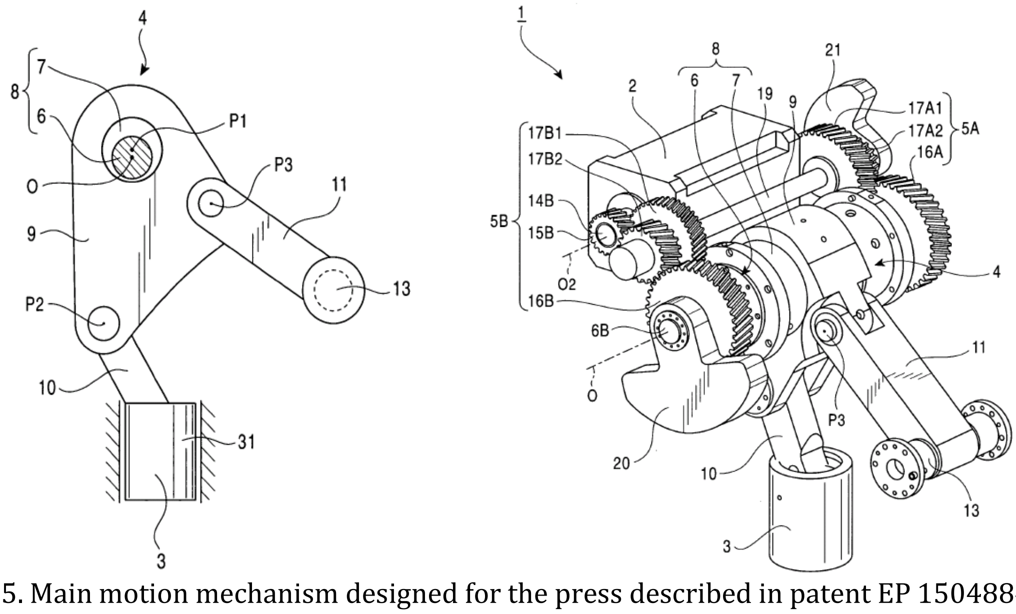


Fig. 5. Main motion mechanism designed for the press described in patent EP 1504884 [3]

Figure 6 present a schematic of the transformation mechanism of the press in patent EP 1504884; the bars and joints are denoted in the figure as in the patent. Eccentric 7 is a driving element for both mechanism O-P_1-P_2-O_1 and mechanism O-P_1-P_2-3.

The double composed transformation mechanism consisting of two bar mechanisms can be found in several other patents and utility models. The respective mechanisms do not differ in structure, but only by the orientation of the bars in the plane, by the ratios of some of the bars, by the position of the fixed joints in the plane, or by constructive details. This is illustrated further on by a several relevant examples:

- in utility model CN 202934823 U [4], Figure 7, the first bar mechanism consists of the eccentric of the main shaft with attached gear 4 that drives the shaft, bar 6 and lever bar 7, and the second mechanism consists of the eccentric of the main shaft, bar 6 and lever bar (connecting rod) 8, the slide being the final element driven in view of deployment. The comparison to the toggle mechanism used in extrusion presses is unavoidable;

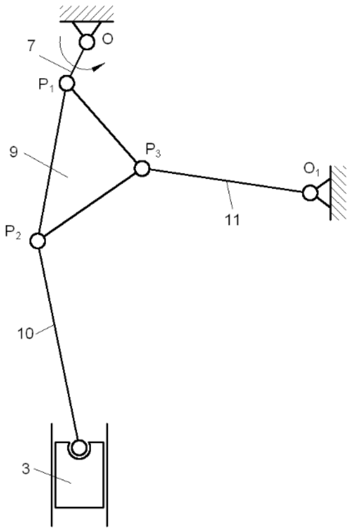


Fig. 6. Schematic of the double composed transformation mechanism used on the press that is the object of patent EP 1504884 [3]

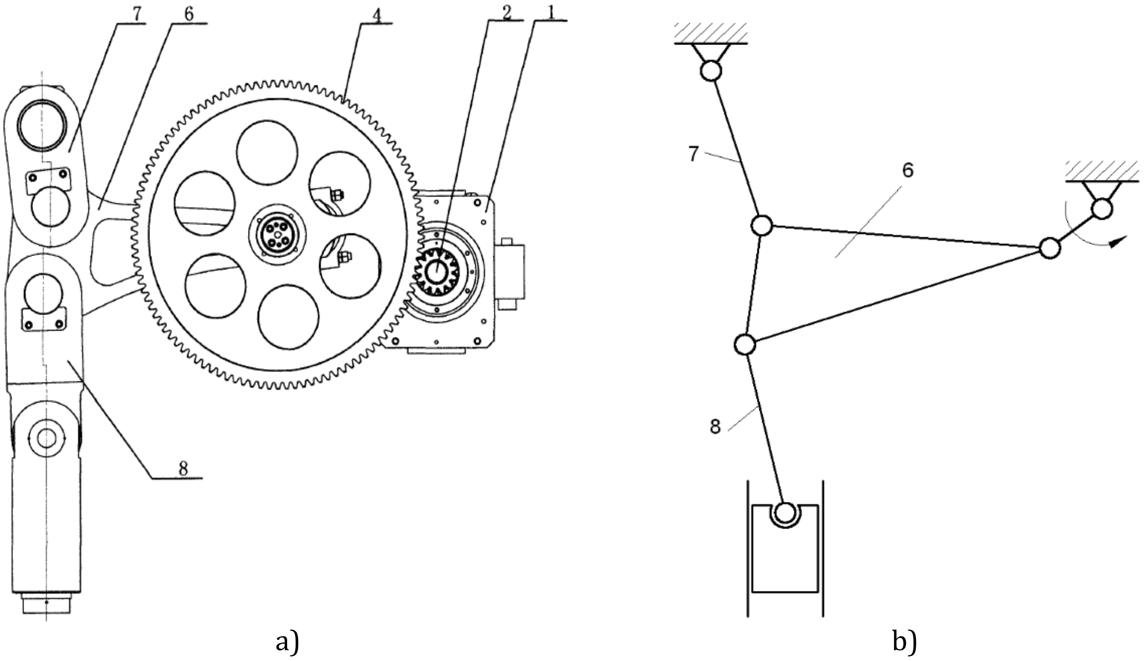


Fig. 7. Slide driving mechanism consisting of two bat mechanisms; a) utility model CN 202934823 U [4]; b) schematic

- as regards the transformation mechanism, there is no significant difference between the solutions proposed by the utility models CN 202934823 U presented above, and CN 202448365 U [5], Figure 8;
- a particular solution - construction and the reciprocal positions of the joints related - is identified in the double composed mechanism presented in patent US 7004006 [6]. Figure 9 presents the constructive solution of the mechanism, also in 3D. Fig. 10 (on the left) contains the connecting rod

curve, and the graph (of the displacement, the velocity or the available force) relevant for the discussed patent. In the case of patent US 7004006, Figure 10 shows (on the right) the graph of displacement that reveals both the increase in duration of the descending stroke and the decrease of the raising stroke duration, as well as the "linearization" to a large extent of the law of displacement of the slide during the descending stroke, with the immediate effect of a reduced variation of the slide velocity for that segment of the stroke;

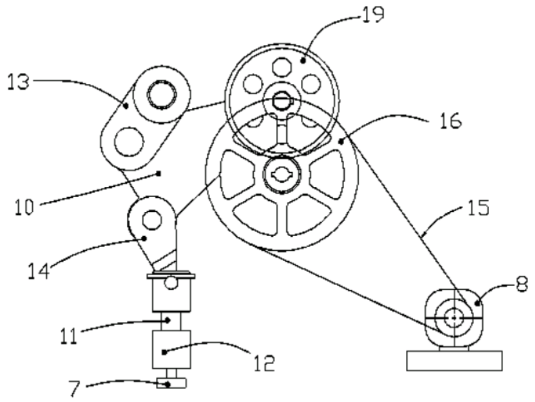


Fig. 8. The transformation mechanism on the press described by the utility model CN 202448365 U [5]

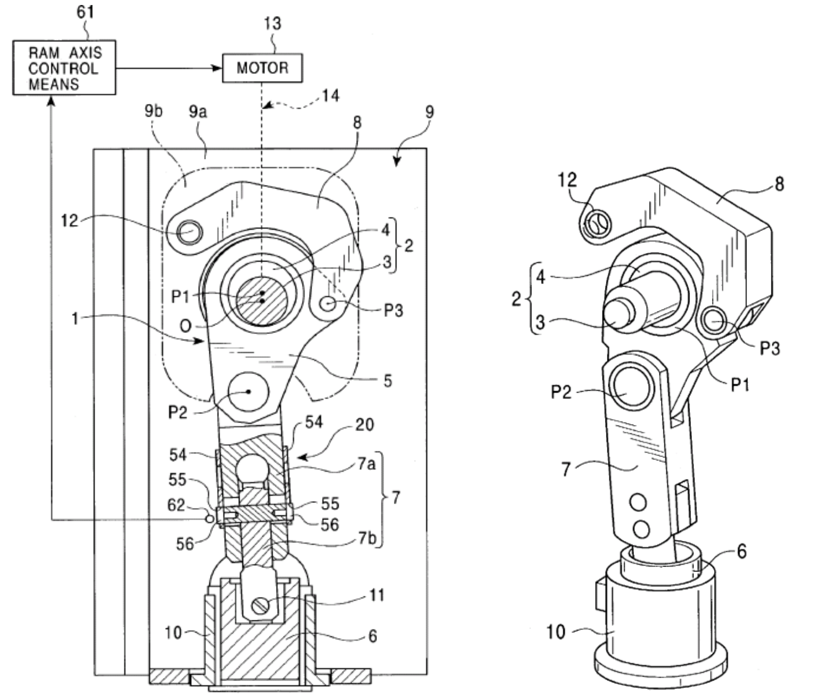


Fig. 9. The constructive solution of the mechanism of a mechanical press, including a 3D representation, proposed and protected by invention patent US 7004006 [6]

- noteworthy are those patents referring to bar mechanisms, in particular used on presses, accompanies by graphs that contain also the connecting-rod curves described by the axes of the mechanism joints or by particular points of one or more bars of those mechanisms, as well as the graphs of displacement, velocity and even of the available force, possibly representing also the similar graphs of a mechanism of reference, like for example those of the simple crank - connecting rod - slide mechanism of summation type. An example in this respect can be patent US 4107973 [7]. The transformation mechanism, shown in Figure 11 as a constructive solution and as a schematic that includes the connecting rod curves of the mobile axes and joints, consists of the bar mechanisms OABC and OADE. Joints A, B and D are attached to one another, and are materialised by bar 50. Figure 12 presents the graphs of the displacement and the velocity that describe the motion of slide 24 driven by the discussed mechanism, and includes a comparison to the corresponding graphs described by a simple crank - connecting rod - slide mechanism of summation type;

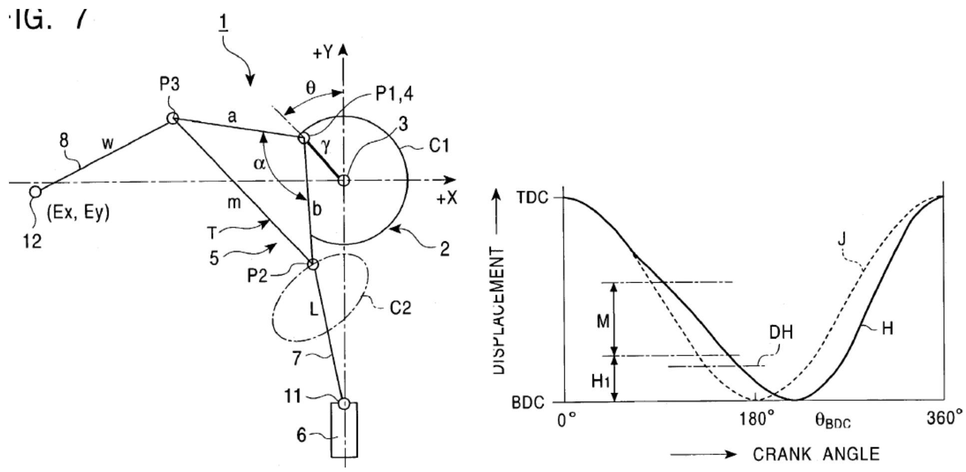


Fig. 10. Schematic of the mechanism that is the object of invention patent US 7004006 and the displacement graph associated to the motion of its slide [6]

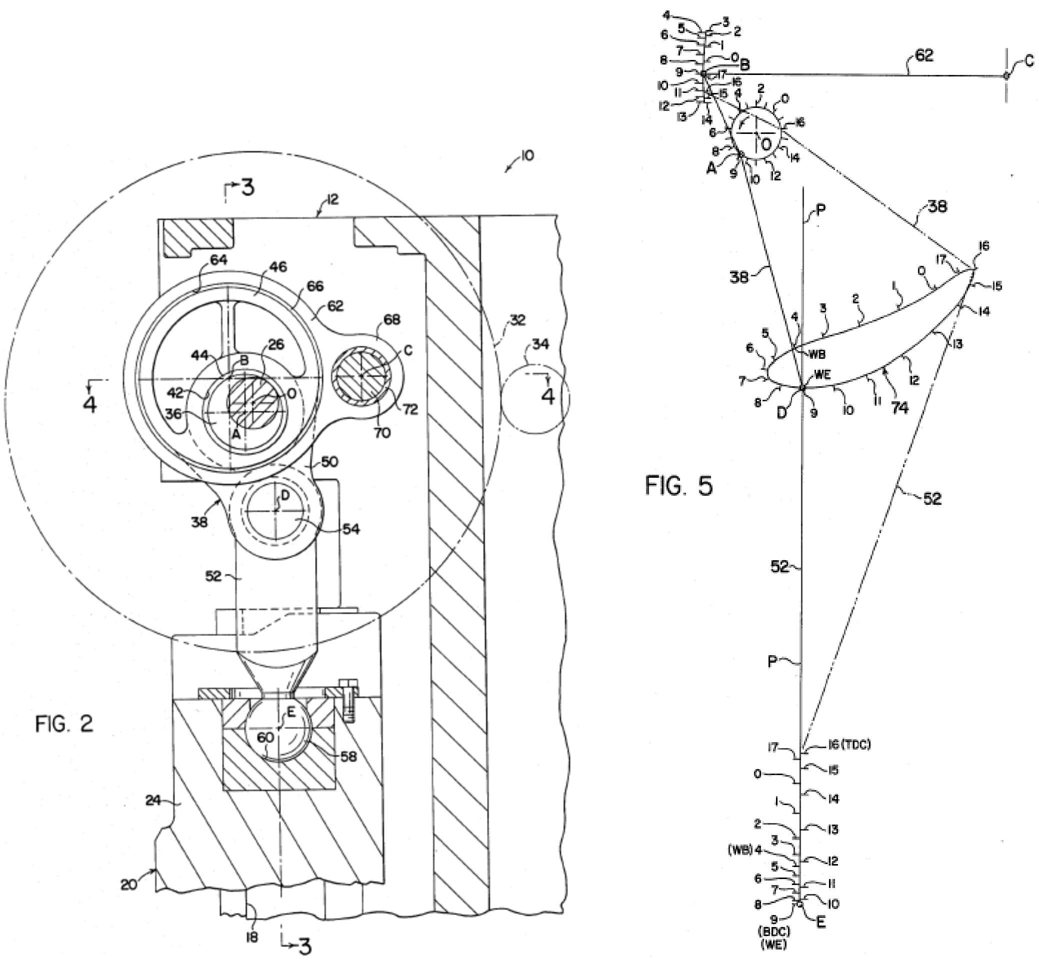


Fig. 11. Transformation mechanism - constructive solution and schematic accompanied by the connecting rod curves of the joints - claimed by patent US 4107973 [7]

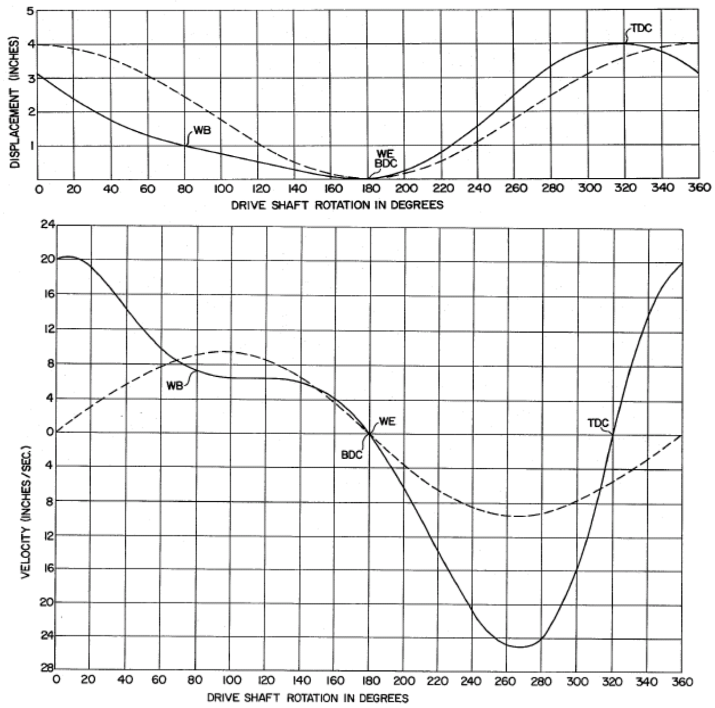


Fig. 12. Graphs of displacement and velocity corresponding to the transformation mechanism of the mechanical press that is the object of invention patent US 4107973 [7]

- in worldwide literature, several patents and utility models are identified having simple or even simplistic graphical representations of the double composed mechanism consisting of two bar mechanisms, possibly found in identical or similar form in several distinctive documents. A group of developments of this type, Figure 13, is formed of patents CN 102717016 [8] and CN 102717017 [9], as well as utility models CN 202045893 U [10] and CN 202045894 U [11];

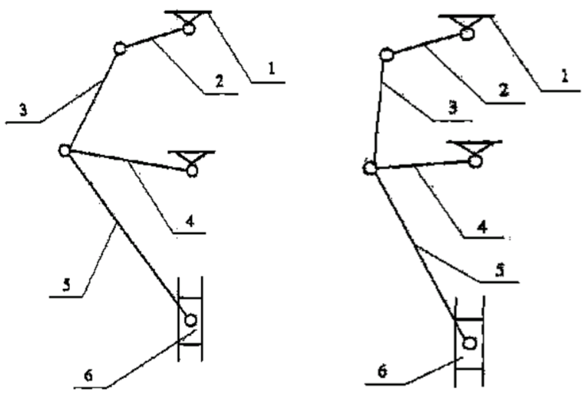
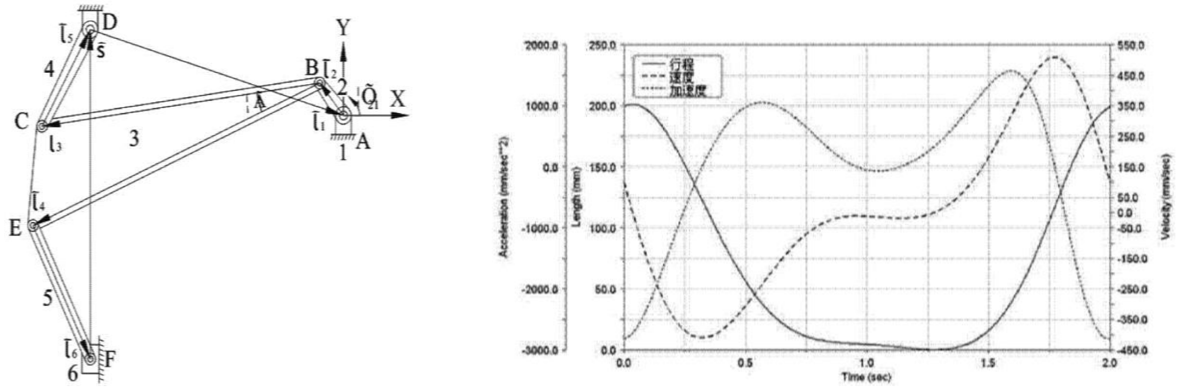


Fig. 13. Transformation bar mechanisms,
according to patents CN 102717016 [8] and CN 102717017 [9]

- the double composed mechanism consisting of two bar mechanisms is also the subject - in patent CN 102126301 [12] - of an optimum design based on the closed vector contour method. Vectors $\vec{i}_1$, $\vec{i}_2$, $\vec{i}_3$ and $\vec{i}_5$ are associated to the bars of ABCD bar mechanism, Figure 14a, and vectors $\vec{i}_2$, $\vec{i}_4$, $\vec{i}_6$ and the resulting vector of the sum $\vec{s} + \vec{i}_1$ are associated to the bars of ABEF bar mechanism. Vector $\vec{i}_1$ is invariable. Vectors $\vec{i}_3$ and $\vec{i}_4$ are attached one to another. The variation of vector $\vec{s}$ determines the motion law of slide 6 of the mechanism. For a given dimensioning of the mechanism that ensures a total stroke of 200 mm, the graph of the displacement, Figure 14b reveals that the useful part of the descending stroke (of about 10 mm) is carried out with reduced and almost constant velocity during ≈12% of the duration of a double stroke. The duration of the descending stroke represents almost 65% of the duration of a double stroke. Under these conditions, the duration of a load stroke represents ≈20% of the duration of the descending stroke;



a) b)

Fig. 14. The transformation mechanism consisting of two bar mechanism according to CN 102126301 [12]
a) representation with vectors; b) graphs of displacement, velocity and acceleration

- directly linked to the mechanism of patent CN 102126301 [12] is also patent CN 102019707 [13] that presents also a constructive solution of a press including the discussed double composed transformation mechanism, Figure 15. Outstanding is also the presence of two wedge mechanisms for two adjustments: adjustment in the vertical plane of the axis of joint 9 (joint D of Figure 14a), the translation of the wedge in the horizontal plane being achieved by a screw-nut mechanism, and the adjustment of the position of slide 1, the position of wedge 2 in the horizontal plane being ensured by hydraulic piston 15. Piston 15 can also have the role of "hydraulic cushion" protection system against force overload [14].

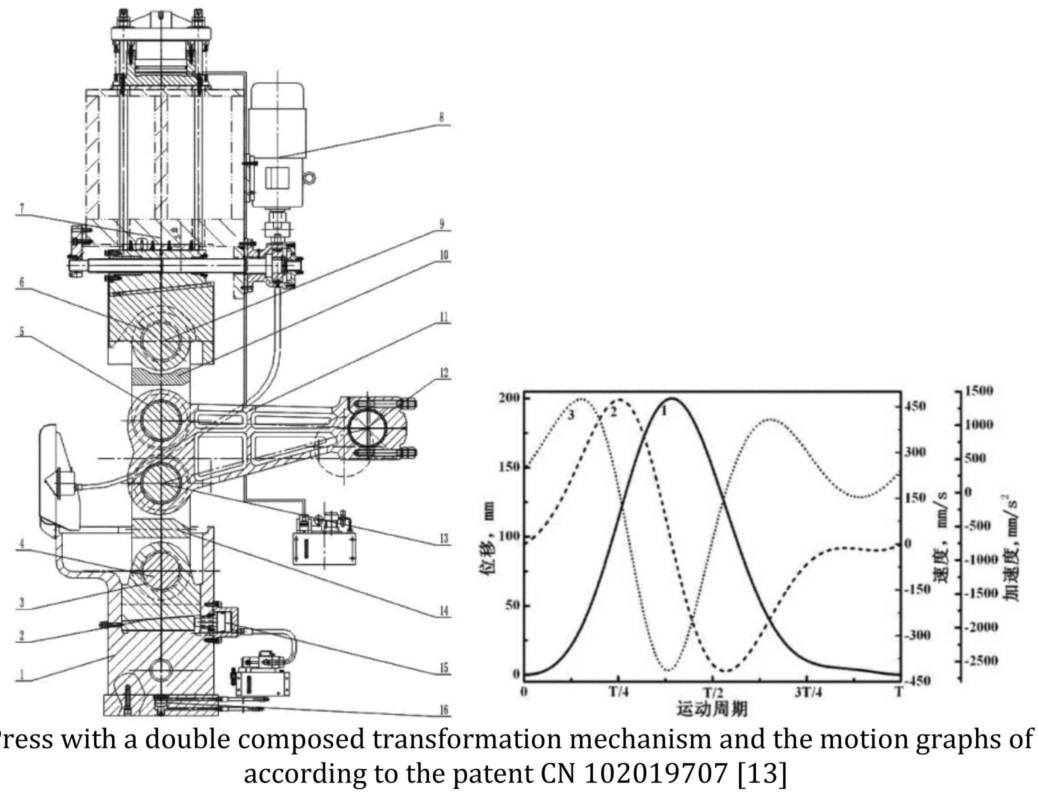


Fig. 15. Press with a double composed transformation mechanism and the motion graphs of its slide, according to the patent CN 102019707 [13]

3.2. Triple composed transformation mechanisms

The triple composed mechanisms for mechanical presses identified in the international patent library consist of a sequence of two bar mechanisms and a final crank - connecting rod - slide mechanism. The first bar mechanism transforms the rotation of the main shaft into the oscillation of a lever bar, the second bar mechanism modifies this motion and transmits it to another lever bar, the latter being attached or even identical to the crank of the final mechanism responsible for transforming the oscillation of the connecting rod into the guided linear translation of the slide.

Patent US 2271771 [15] puts forward a solution of principle and construction, Figure 16, mainly aimed at the possibility of the continuous adjustment within a certain range of the slide stroke length. A first bar mechanism transforms the rotation of the main shaft 25 into the oscillation of lever bar 32. The second bar mechanism transmits (by means of bar 35) and transforms this oscillation into the oscillation of crank 18, while the final mechanism consisting of crank 18 - connecting rod 20 causes the reciprocating linear translation motion of slide 12. The adjustment of the slide stroke length depends on the characteristics of the bar mechanism consisting of lever bar 45, bar 35 and crank 18. The length of lever bar 45 can be adjusted by turning bar 35 in relation to joint 41, thus modifying of the distance between axes 33 and 42 and implicitly modifying the law of transmission of the oscillation of lever bar 45 to crank 18. The oscillation amplitude of the latter is modified, and consequently also the length of the stroke of slide 12. A secondary effect, desired or not, is the modification of the motion law of the slide.

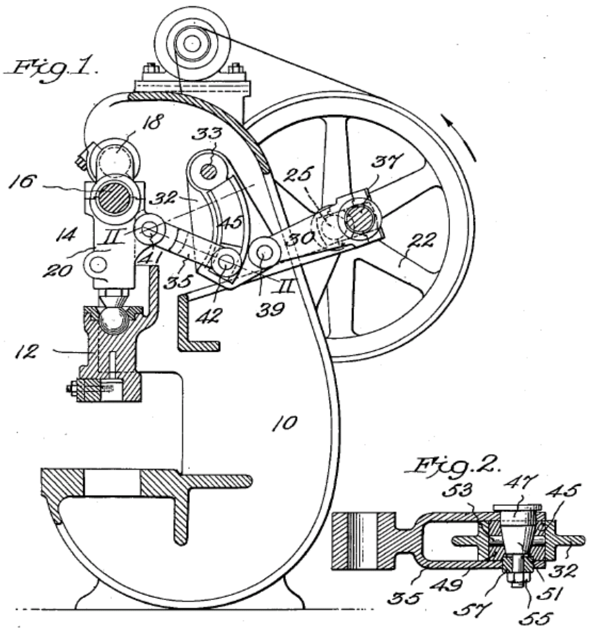


Fig. 16. Mechanical crank press with a bar mechanism for the adjustment of the slide stroke length. Solution put forward by patent US 2271771 [15]

It is known that typically the slide stroke length is adjusted only on mechanical crank presses with a C-frame. For this mechanism with eccentric, bushings are used, which, however, is not the subject of this paper. The solution proposed by patent US 2271771 is an alternative to the eccentric bushing mechanism, without a significant impact on global practice.

A constructive solution of a C-frame mechanical press with main shaft parallel to the front face, where the triple composed bar mechanism is evident and explicit can be identified in patent US 2562044 [16], Figure 17. The first bar mechanism transforms the rotation of the main shaft 16 into the oscillation of the lever bar 70. The second bar mechanism modifies and transmits this motion to crank 50, and the crank - connecting rod - slide mechanism transforms the oscillation of crank 50 into the reciprocating linear translation of slide 14. During the load stroke crank 50 is actuated by pushing, but the mechanism can be reconfigured such as to allow actuation by pulling.

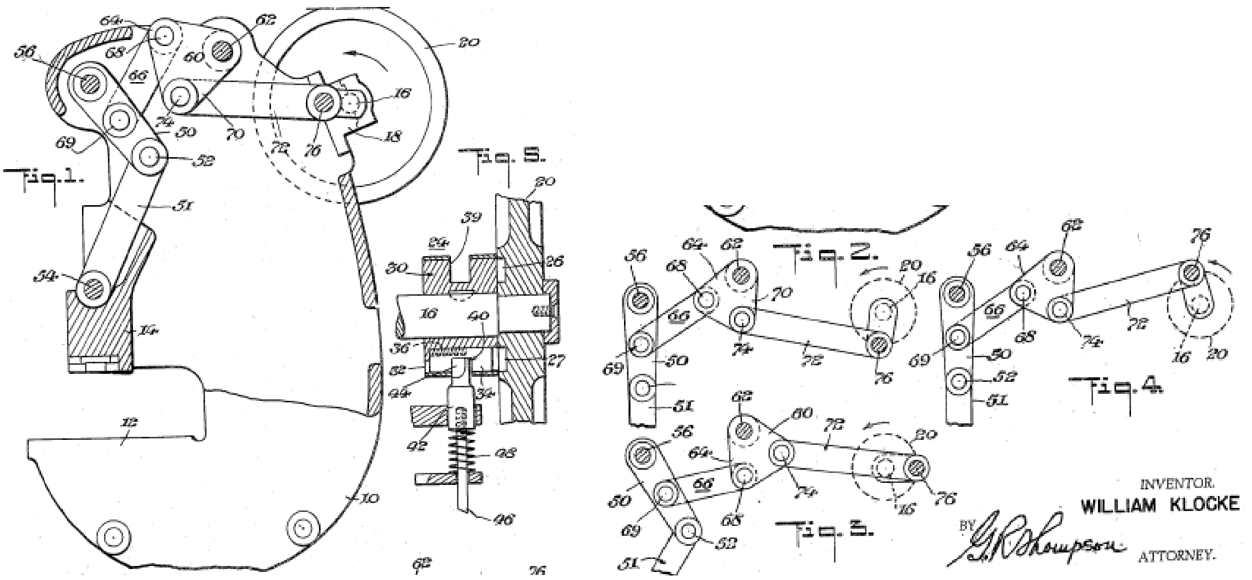
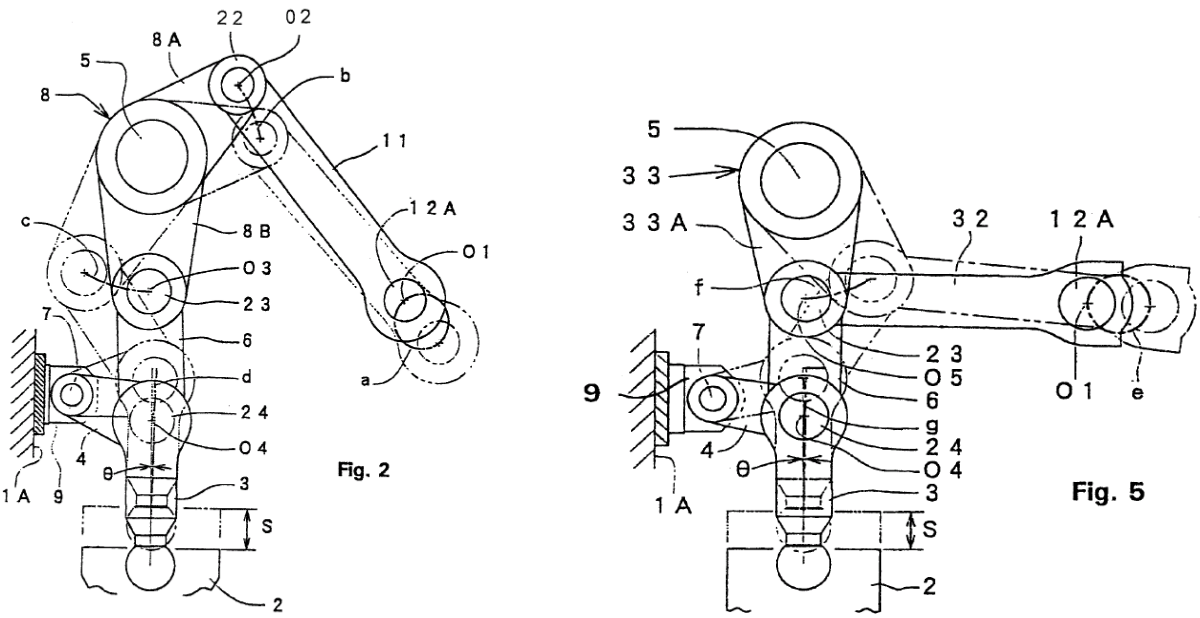


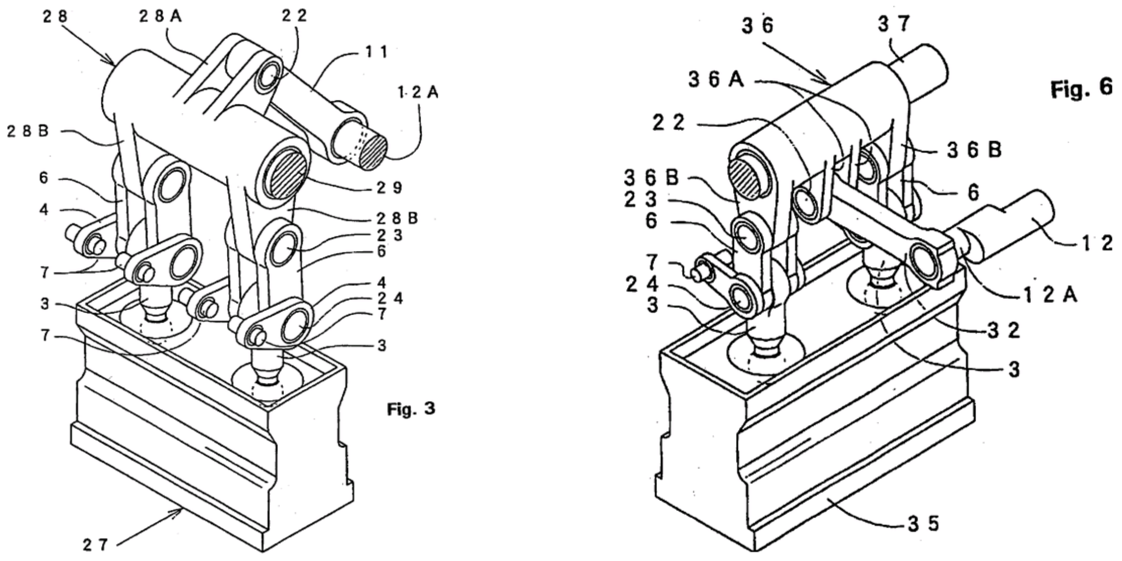
Fig. 17. Mechanical crank press with a triple composed mechanism (two bar mechanisms and a crank mechanism) for modifying the law of motion of the slide, according by patent US 2562044 [16]

A "knuckle" mechanical press where the triple composed transformation mechanism consists of two bar mechanisms and a crank - connecting rod - slide mechanism proposed in two constructive variants, Figure 18, is protected by an international patent held by the company Aida Engineering, registered in several countries, like Germany (DE 19913710 [17]), and the United Stated (US 6012322, [18]). The whole assembly is compact, suggesting a good proportionality and stiffness. The press has either a single knuckle (Figure 18a), consisting of bar 6, lever bar 4 and the connecting rod 3, all of which share the axis joint O4, or two knuckles corresponding to the variant of the mechanism shown in Figure 18b, the second knuckle consisting of bars 32, 36A, 36B and 6, all sharing the axis joint O5. Attached to the same body 36, bars 36A and 36B are distinctive, but have the same length and orientation, Figure 19b. To be noted is the fact that the identity of length and orientation of bars 36 and 36B is merely a particular case, technologically beneficial, while the mentioned bar may differ as to their length, orientation or both.



a) b)

Fig. 18. Triple composed transformation mechanism described in patents DE 19913710 [17] and US 6012322 [18], presented for the two extreme positions of the slide

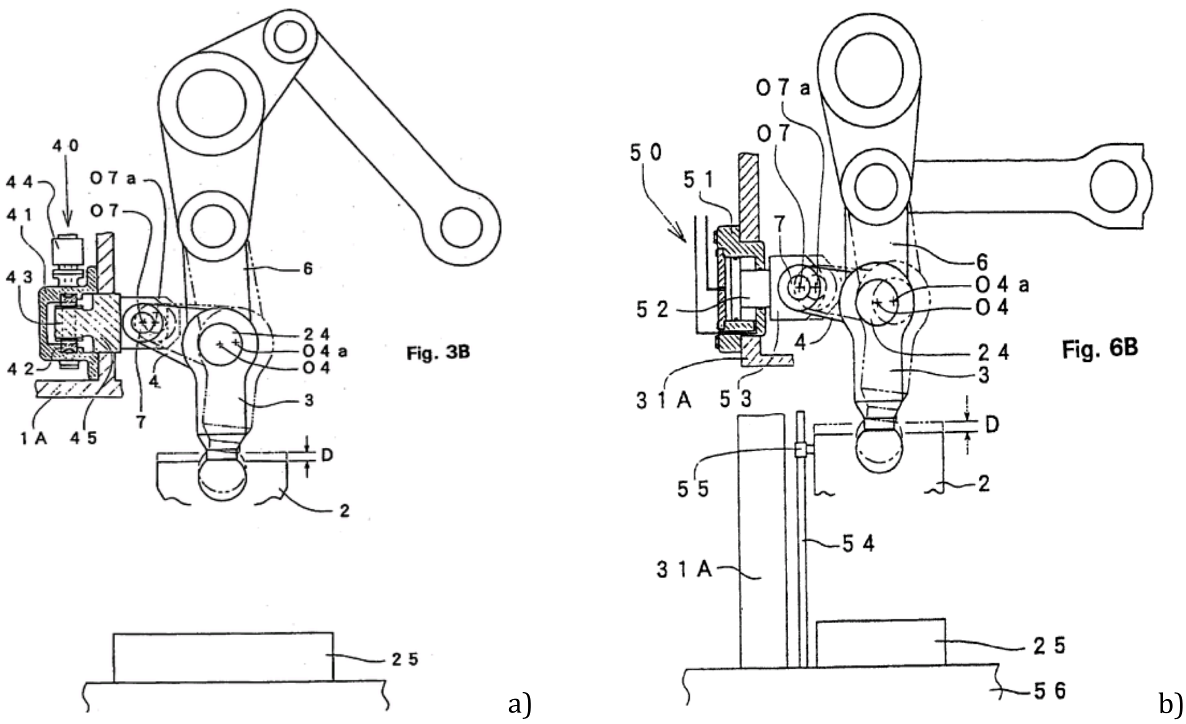


a) b)

Fig. 19. Slide driving mechanism according to patent US 6012322, in 3D representation [18]

The presented triple composed mechanism can endow a single connecting rod press, as shown in Figure 19, or a press with two connecting rods and a slide of increased length. By extension, the mechanism could allow also the construction of a press with three "in-line" connecting rods, a case however, rarely encountered in practice.

The joint O7 of the bar (bars) 4 can be fixed or adjustable as to its position, as adjustment possibility of the bottom dead end position of the slide, Figure 20. Patent DE 19913710 [17] provides the possibility of translating joint O7 in the horizontal plane perpendicular to the direction of motion of the slide, by means of either an eccentric mechanism, Figure 20a, or a hydraulic piston, Figure 20b. In this latter case piston 52 can also or only play the role of a "hydraulic cushion" type protection system against force overload [14].



a) b)

Fig. 20. Solutions for the adjustment of the position of the slide proposed by patent US 6012322 [18]

A triple composed mechanism of the analysed type endows also the two connecting rod press described in patent EP 1043148 [19], Figure 21. The first bar mechanism consists of crank 16b of the main driving shaft 16, bar 26 and lever bar 32. The latter, together with bar 34 and median crank 20b of the crankshaft form the second bar mechanism, that drives the oscillation of shaft 20. Slide 22 is driven by two identical crank - connecting rod - slide mechanisms, each consisting of a crank 20c, a short connecting rod 40 and a rod 24 guided on frame 14 distinctive from the guides of slide 22. The two rods 24 are attached to slide 22.

The constructive solution including a shortened connecting rod (consisting of the actual connecting rod 40, short and jointed, extending to a rod 24 guided on the machine frame independent of the guides of the slide which is driven by it), rather frequently encountered in closed frame mechanical presses favours reducing the bulk of the press and more importantly, contributes to an improved guiding of the slide.

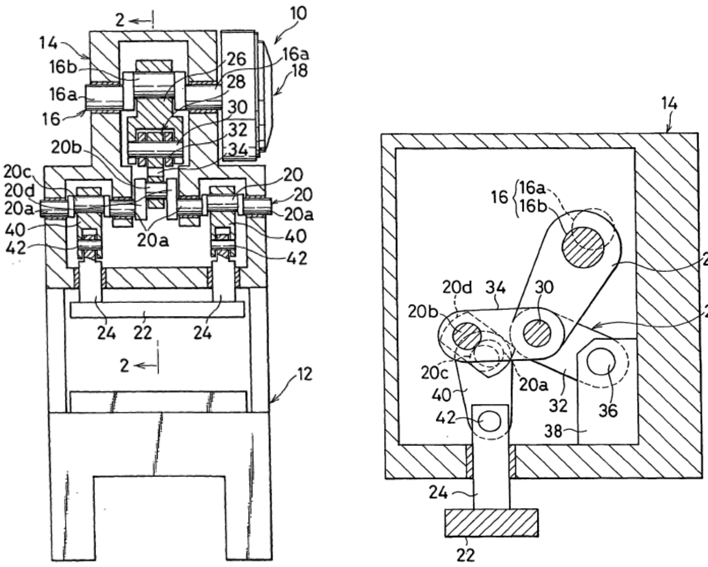


Fig. 21. Triple composed transformation mechanism, according to patent EP 1043148 [19]

A triple composed transformation mechanism consisting of three bar mechanisms designed for a closed frame mechanical press with one, two or even four connecting rods is described in patent US 4138904 [20]. The schematics show only the proposed constructive solution of the mechanism, Figure 22, the structure of the mechanism and the connecting rod curves of the mobile joint axes, Figure 23, the graphs of displacement and velocity, Figure 24, as well as the graph of the available force.

The first bar mechanism, EPQA, consisting of input shaft 27 - the main shaft, the eccentric 30, bar 37 and lever bar 40, transforms the continuous rotation of the main shaft 27 into the oscillation of lever bar 40. The second bar mechanism, ADFG, consisting of bars 41 (AD) (attached to bar 40 (QA)), 43 (DF) and 32 (segment FG), transform the oscillation of lever 41 and convey it to bar 32. The last bar mechanism, EGHC, consisting of the eccentric EG of bushing 29 attached to the main shaft 27, segment GH of bar 32, connecting rod 35 (HC) and the guided rod 13 ensuring the connection to slide 12. The axes of joints A and E can be in the same horizontal plane or not, a detail illustrated in Figure 23.

Extremely obvious is the similarity of the transformation mechanism presented in Figure 22 and the type II transformation mechanism [2] used for driving the exterior slide in some double action presses (mechanical presses for deep drawing).

The graphs of displacement and velocity, Figure 24, of the slide driven by such a mechanism are presented by direct comparison to the graphs corresponding to the simple crank mechanism of summation type.

Another transformation mechanism consisting of three bar mechanisms designed for a short connecting rod press is described in patent US 3572137 [21], where the construction of the transformation mechanism is presented, Figure 25, the graphs of displacement and velocity, Figure 26, but not also the connecting rod curves associated to the axes of the joints.

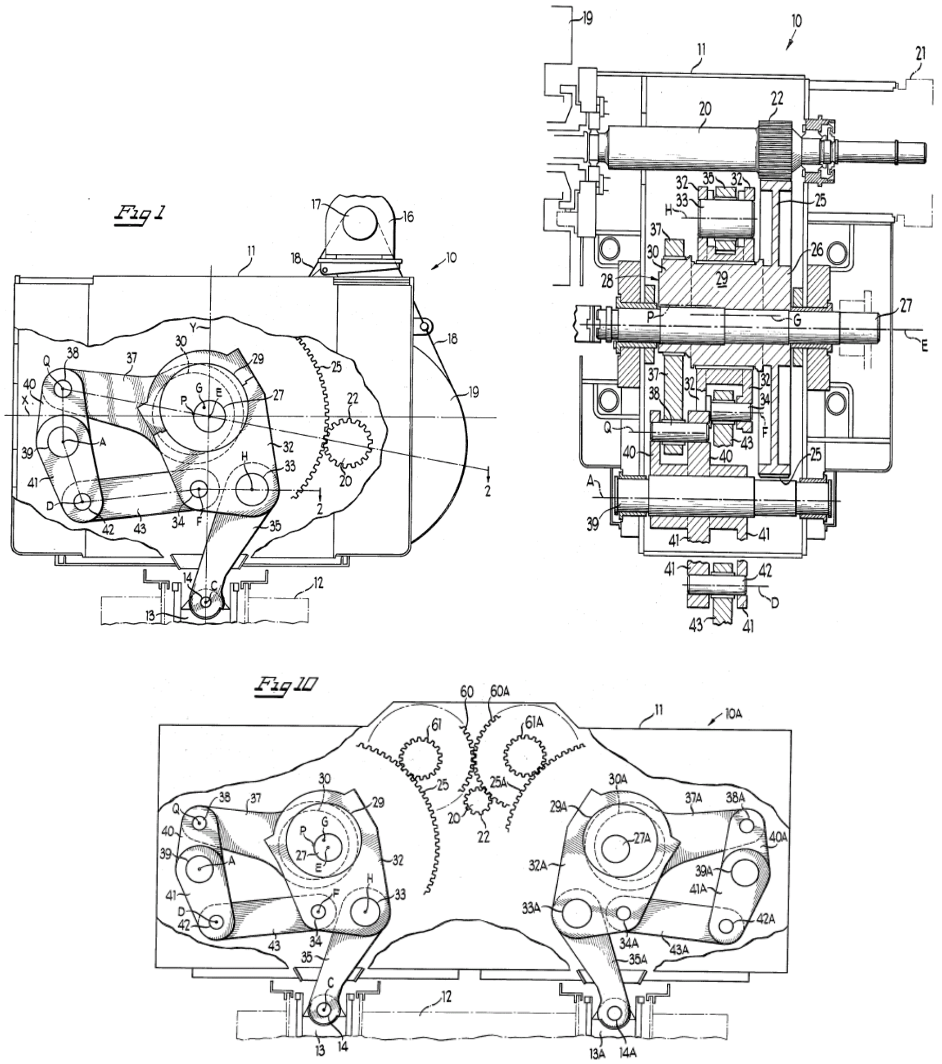


Fig. 22. Constructive solution of the bar mechanism claimed by patent US 4138904 [20]

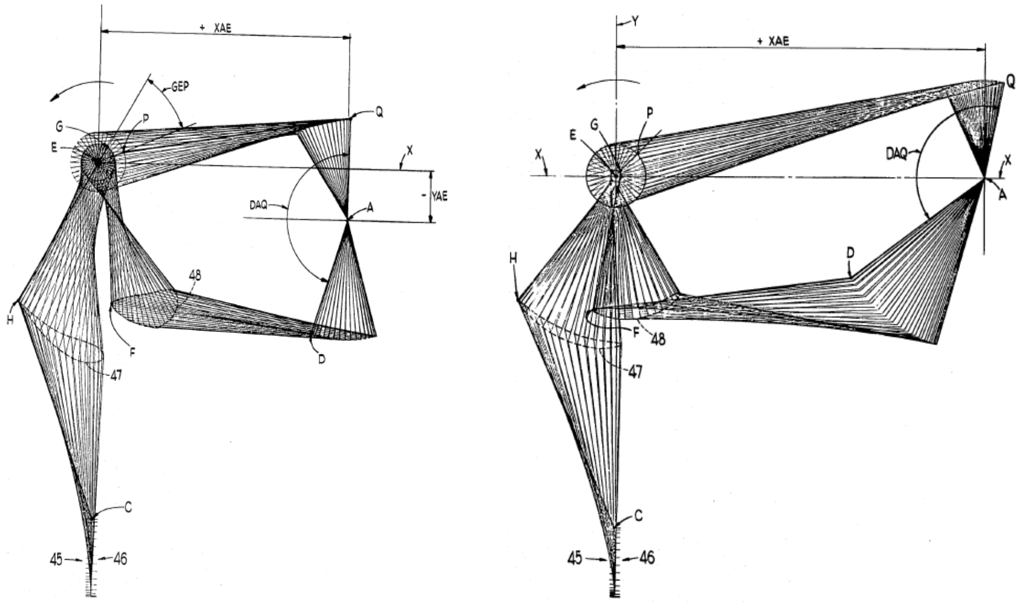


Fig. 23. Structure of the mechanism protected by invention patent US 4138904 and the connecting rod curves of the axes of its mobile joints [20]

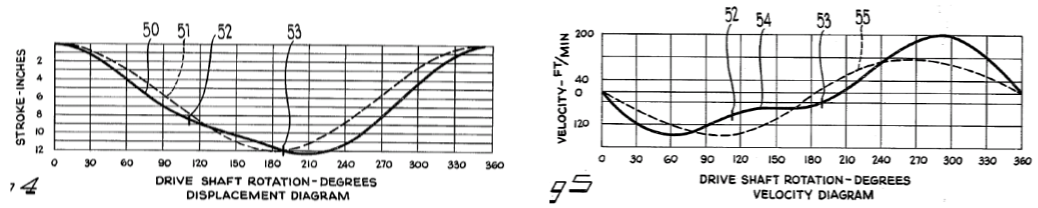


Fig. 24. Graphs of displacement and velocity of a mechanical press described by patent US 4138904 [20]

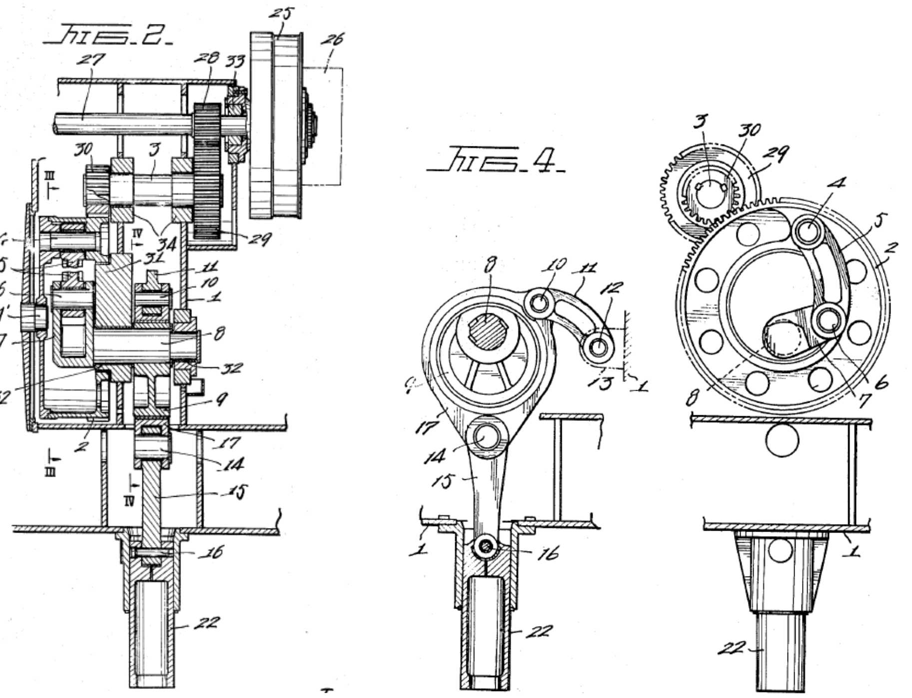


Fig. 25. Constructive solution of the transformation mechanism of the mechanical press described in invention patent US 3572137 [21]

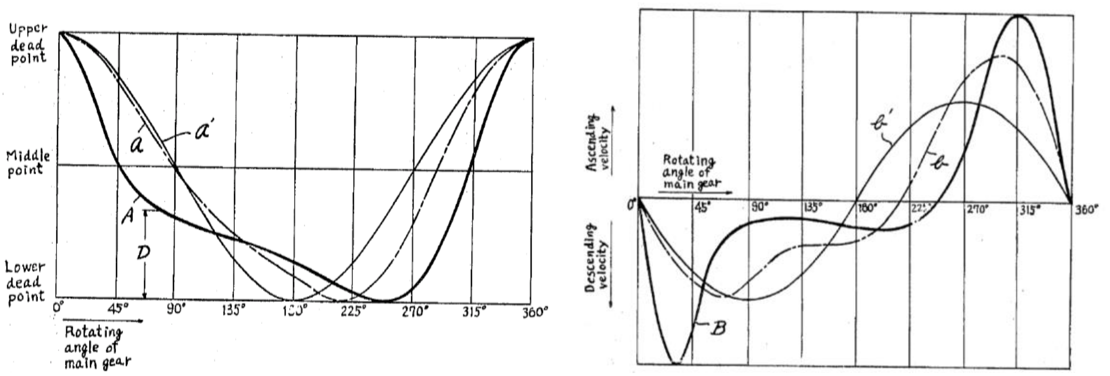


Fig. 26. Graphs of displacement and velocity of the slide of the mechanical press described by patent US 3572137 [21]

The first bar mechanism (consisting of gear 2, bar 5, bar 7 and shaft 8) of the transformation mechanism is a highly particular one: it transforms the uniform rotation of gear 2 into the non-uniform rotation of shaft 8. Gear 2, and the entire assembly attached to it, is driven by pinion 30 and plays the role of the input shaft to the transformation mechanism. Gear 2 is supported on the frame by bearings 31 and 31'. The second bar mechanism - consisting of shaft 8, eccentric bushing 9 (as a rotating bar), bar 17 (the "materialises" the distance between the axis of the connecting joint to the eccentric bushing 9 and the axis of joint 10), bar 11 and joint 12 ensuring the connection to the frame - transforms the non-uniform rotation of shaft 2 into the rotation-translation of bar 17, of interest being the displacement of the axis of joint 14 that links to connecting rod 15. The third bar mechanism - consisting of bar 11, bar 17 (the section that materialises the distance between the axes of joints 10 and 14), the shortened connecting rod 15 and the guided rod 22 (that is attached to the slide) - transforms the rotation-translation of bar 17 into the guided translation of rod 22.

To be noted is the fact that the displacement and velocity graphs (A and B, respectively, Figure 26) corresponding to the mechanism are presented in comparison to not only the graphs (a' and b', respectively) corresponding to a crank-type slide drive mechanism, but also compared to a conventional link-type slide drive mechanism (curves *a* and *b* of Figure 26).

4. Conclusions

Mechanical presses are widely spread machine-tools used in machines manufacturing and numerous other industrial branches. A characteristic of mechanical presses is the transformation mechanism included by their structure, which transforms the uniform rotation of the main shaft into the guided translation of a slide. The majority of mechanical presses deploy a crank - connecting rod type transformation mechanism. In many applications, the law of motion ensured by this mechanism is not the most adequate one, mainly because of the large variation of slide velocity during the load stroke and the relatively reduced weighting of the duration of this part of the stroke in relation to the total duration of a double stroke.

Over time various researchers have designed more complex bar transformation mechanisms for mechanical presses, creatively combining bar and crank mechanisms in various configurations in order to determine motion laws of the slide closer to an imposed or assumed optimum.

In global patent literature several solutions (including constructive ones) of double composed transformation mechanisms for mechanical presses are identified, consisting of a sequence of two mechanisms, the former being a bar mechanism and the second a crank - connecting rode one [2], or both being bar mechanisms [3-9, 12, 13]. The first bar mechanism transforms the uniform rotation of a main shaft into the oscillation of a lever bar, and the second - crank or bar mechanism, as the case may be - modifies the oscillation motion and transmits it to a slide in form of a guided translation motion.

Also, constructive solutions of triple composed transformation mechanisms for mechanical presses are identified, consisting of a sequence of three mechanisms, the first two being bar mechanisms and the third a crank mechanism [15-19, 21] or also a bar mechanism [20]. The first bar mechanism has mainly the role of transforming the uniform rotation of a main shaft into the oscillation of a lever bar, the second bar mechanism has the role of modifying the oscillation and transmitting it also in oscillating form to another lever bar, and the third, crank or bar mechanism, as the case may be, has the role of modifying this latter oscillation and of transmitting it to a slide as a guided translation motion.

It is to be expected that creative research will yield new composed transformation mechanisms for mechanical presses with a motion law of the slide customised for specific applications.

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