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DETERMINATION OF CRANK PRESS FLYWHEEL CHOICE CRITERIA

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Abstract: *The analysis of running conditions of the flywheel systems by taking into consideration of the required characteristics of the working conditions is presented in the paper. The influence of the irregularity over the working conditions among the ratio between the working period and the idle period of the system is taken into consideration. The intercommunication between the required irregularity by the working in proper conditions of the flywheel system and the accomplishing possibilities allowed by the driving system for achieving the desired operating conditions had been considered.*

Key words: *optimal conditions, irregularity, engine slip, flywheel, mechanical work.*

1. INTRODUCTION

The flywheel systems are mean to ensure the dynamical balance of the machines and installations so that at the loading variations that must be fulfilled to be an uniform charging of the mechanisms' elements. The flywheel problem is treated theoretically and the accomplishing conditions in a dynamical system are emphasized generally [1–4].

In the present paper an analysis of the criteria that must be considered for establishing the flywheel dimensions, in the concrete case of the crank mechanical presses, has been done. For this goal, the conditions of the required deformation mechanical work accomplishment for a certain press and the kinematics particularities of the deformation task had been considered. The scope had in view is to obtain some rational solutions accordingly with the different values of the imposed deformation forces at the presses. The paper allows the development in future of some research that could ensure to getting of presses building with a minimal energetic consuming.

2. FINDING OUT OF THE DYNAMIC EQUILIBRIUM CORRESPONDING TO THE WORKING STROKE

At the work of the crank mechanical presses the flywheel has the role of ensuring the equilibrium of the deformation mechanical work and the maintenance of the uniform character of the slider movement in acceptable technological limits. Thus, it is removed the electric motor overstraining and the appearance of some dangerous dynamical loading and it is ensure the accomplishment of the deformation mechanical work took into consideration at the designing and the construction of the press.

To determine the flywheel it could be express the yield kinetic energy by this in the working stroke under the form (1):

$$J_v \cdot \omega_m^2 \cdot \delta = L_d - \frac{M_{\max} + M_{\min}}{2} \cdot \phi_l , \qquad (1)$$

where: J_v is representing the flywheel moment of inertia; ω_{med} – the medium angular velocity of the motor crank; δ – the flywheel irregularity; L_d – the prescribed deformation mechanical work; $M_{\max}$ – the maximum moment that must be fulfilled by the driving engine in the working period; $M_{\min}$ – the minimum moment developed by the electric engine during the working stroke; ϕ_l – the crank angle corresponding to the maximum working stroke foresee for the press (Fig. 1).

The mechanical energy yields the flywheel during working stroke recovered by the electric engine during the idle running – slider retirement. It was taken into consideration that in this time the engine torque varies between $M_{\max}$ value existing at the end of the working

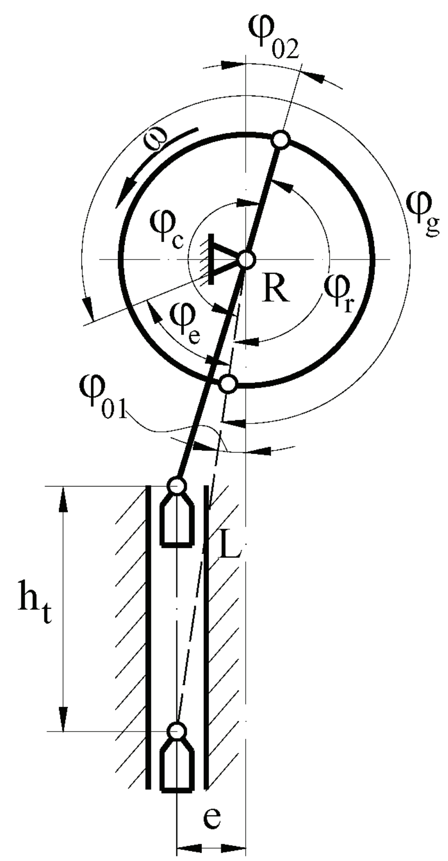

Fig. 1. The kinematics scheme of the press.

stroke (when the engine speed is minimal) and $M_{\min}$ at the moment when it has been accomplished the integral recovery of the energy yielded by the flywheel.

As a result, the next relationship can be written:

$$\frac{M_{\max} + M_{\min}}{2} \cdot \phi_r = J_v \cdot \omega_{med}^2 \cdot \delta, \tag{2}$$

where: $\phi_r = 2 \cdot \pi - \phi_l - \phi_0$ is representing the crank rotational angle corresponding with the period when the retrieve of the kinetic energy yielded by the flywheel (Fig. 2); ϕ_0 is corresponding to the crank rotational angle from the moment when it took place the recovery of the energy yielded by the flywheel till the beginning of a new machining cycle. Generally, it can be considered $\phi_0 = 10°$.

Therefore, it results the equality:

$$\frac{M_{\max} + M_{\min}}{2} = \frac{J_v \cdot \omega_{med}^2 \cdot \delta}{\phi_r}. \tag{3}$$

By effecting the corresponding replacements in (1) relationship:

$$J_v \cdot \omega_{med}^2 \cdot \delta = L_d - \frac{J_v \cdot \omega_{med}^2 \cdot \delta}{\phi_r} \cdot \phi_l. \tag{4}$$

It results:

$$J_v \cdot \omega_{med}^2 \cdot \delta \left(1 + \frac{\phi_l}{\phi_r} \right) = L_d. \tag{5}$$

Consequently, the kinetic energy yield by the flywheel during the deformation mechanical work:

$$J_v \cdot \omega_{med}^2 \cdot \delta = \frac{L_d}{1 + \dfrac{\phi_l}{\phi_r}}. \tag{6}$$

This relationship can be written under the form:

$$J_v \cdot \omega_{med}^2 \cdot \delta = \frac{L_d}{\phi_r + \phi_l} \cdot \phi_r. \tag{7}$$

If it is taken into consideration the fact that, generally, the ϕ_l angle is according with the $\phi_l = 30°$ value and that it's maximum value can reach $\phi_l = 90°$, by effecting the correspondent replacements in (7) relationship, it will be obtain:

for

$$\phi_l = 30° \Rightarrow J_v \cdot \omega_{med}^2 \cdot \delta = \frac{320°}{350°} \cdot L_d \cong 0{,}914 \cdot L_d;$$

for

$$\phi_l = 30° \Rightarrow J_v \cdot \omega_{med}^2 \cdot \delta = \frac{260°}{350°} \cdot L_d \cong 0{,}742 \cdot L_d;$$

It comes out that in conditions of maximum stroke if they are considered loses by friction according to a press total efficiency of $\eta_t = 0.7$ it results that the flywheel kinetic yield energy ensure the accomplishing of approximately half of the L_d mechanical work (8′).

For smaller strokes, evidently, the weight of the deformation mechanical work achieved by the flywheel kinetic energy is smaller (8″):

$$E_{cv} = \eta_t \cdot 0{,}94 \cdot L_d \cong 0{,}64 \cdot L_d, \tag{8′}$$

$$E_{cv} = \eta_t \cdot 0{,}742 \cdot L_d \cong 0{,}52 \cdot L_d. \tag{8″}$$

The constructive dimensions of the flywheel can be estimated by taking into account the relationship (9):

$$J_v = \frac{L_d}{\omega_{med}^2 \cdot \delta} \cdot \frac{\phi_r}{\phi_l + \phi_r}. \tag{9}$$

It comes out that these are determined by the working angle ϕ_l, the angular speed ω_{med}, respectively the number of double strokes per minute n_{cd} and the flywheel allowable irregularity δ.

By taking into consideration the recommended values for the flywheel irregularity of the mechanical presses $\delta \in (12 \div 15)\%$ and the corresponding values of the medium angular speeds, the next relationships can be written:

$$\delta = \frac{n_{\max} - n_{\min}}{n_{med}};$$

$$n_{med} = \frac{n_{\max} + n_{\min}}{2} \Rightarrow \delta = \frac{2 \cdot (n_{\max} - n_{\min})}{(n_{\max} + n_{\min})}.$$

But, the next relationship can be express:

$$n_{\max} = n_0 \cdot (1 - s_{\min}); \quad n_{\max} = n_0 \cdot (1 - s_{\min}).$$

Therefore, the irregularity can be express by using the next relationship:

$$\delta = \frac{2 \cdot n_0 \left[(1 - s_{\min}) - (1 - s_{\max}) \right]}{n_0 \left[(1 - s_{\min}) + (1 - s_{\max}) \right]} = \frac{2 \cdot (s_{\max} - s_{\min})}{2 - (s_{\max} + s_{\min})}, \tag{10}$$

where: $n_{\max}$ is representing the engine maximum speed corresponding to the condition in which the flywheel had accumulated the maximum kinetic energy, just before of the beginning of the working stroke; $n_{\min}$ is representing the engine minimum speed corresponding to the end of the working stroke when the flywheel had yield its entire kinetic energy necessary for the achievement of the required deformation task and for the fulfillment of the deformation maximum mechanical work; n_0 – the synchronism speed of the electric engine; $s_{\max}$ – the maximum slip specific for the engine running at maximum torque (maximum load); $s_{\min}$ – the minimum slip of the engine corresponding to the moment when the flywheel kinetic energy had been recovered before the beginning a new working phase.

From the (10) relationship it comes out that the flywheel irregularity will be determined by the running characteristics of the electric engine and more precisely by the speed variations under loading corresponding to $s_{\max}$ and $s_{\min}$ slims, specific to the adopted engine.

By taking into considerations the next relationship:

$$s_{\max} = \frac{n_0 - n_{\min}}{n_0}; \quad s_{\min} = \frac{n_0 - n_{\max}}{n_0} \cong 0{,}2 \cdot s_n; \tag{11}$$

and by effecting the replacements in (10) expression it will be obtained:

$$\delta = \frac{2 \cdot (s_{\max} - 0{,}2 \cdot s_n)}{2 - (s_{\max} + 0{,}2 \cdot s_n)}. \tag{12}$$

As a result, the slip s_{max} is determined as the form:

$$2 \cdot \delta - \delta \cdot s_{max} + 0,2 \cdot \delta \cdot s_n = 2 \cdot s_{max} - 0,4 \cdot s_n \Rightarrow$$
$$s_{max} \cdot (2+\delta) = 2 \cdot \delta + 0,2 \cdot \delta \cdot s_n + 0,4 \cdot s_n \Rightarrow \quad (13)$$
$$s_{max} = \frac{2 \cdot \delta + 0,2 \cdot \delta \cdot s_n + 0,4 \cdot s_n}{2+\delta}.$$

By making the analysis in (10–12) relationships it is emphasized the fact that the flywheel irregularity is influenced by the mechanical characteristic of the electric engine.

A very important parameter is the admissible maximum slip in the operating conditions of the electric engine at maximum torque.

The relationship between the slip and the irregularity is emphasized in Fig. 2, and the influence of the slip over the flywheel moment of inertia is resulted from the diagram presented in Fig 3.

To ensure the best running of the press it is necessary to accomplish the verifying of the condition of the deformation mechanical work achievement and of the angle ϕ_r in which it is fulfilled the recovery of the flywheel yield kinetic energy. For this goal relationships (1) and (2) will be considered and the next requirements:

$$\frac{M_{max} + M_{min}}{2} \cdot \phi_l \geq L_d - J_v \cdot \omega_{med}^2 \cdot \delta, \quad (14)$$

$$\frac{M_{max} + M_{min}}{2} \cdot \phi_r \geq J_v \cdot \omega_{med}^2 \cdot \delta. \quad (14')$$

On consequent, it results:

$$\phi_l \geq \frac{L_d - J_v \cdot \omega_{med}^2 \cdot \delta}{\frac{M_{max} + M_{min}}{2}}, \quad (15)$$

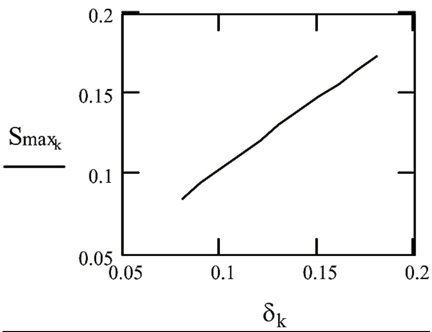

Fig. 2. The connection between the irregularities and the slips is presented.

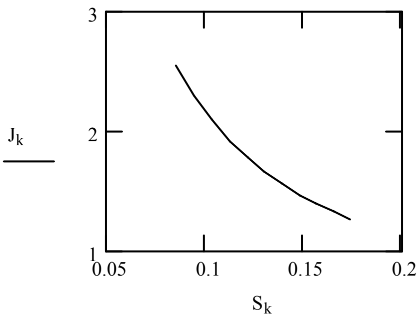

Fig. 3. The influence of the slip over the flywheel moment of inertia.

$$\phi_r \geq \frac{J_v \cdot \omega_{med}^2 \cdot \delta}{\frac{M_{max} + M_{min}}{2}}. \quad (15')$$

By taking into consideration the expression of δ irregularity in (10) relationship, the expressed conditions in (15) and (15′) relationships could be expressed under the form:

$$\phi_l \geq \frac{L_d - 2 \cdot J_v \cdot \omega_{med}^2 \cdot \frac{(s_{max} - s_{min})}{2 - (s_{max} + s_{min})}}{\frac{M_{max} + M_{min}}{2}}, \quad (16)$$

$$\phi_r \geq \frac{2 \cdot J_v \cdot \omega_{med}^2 \cdot \frac{(s_{max} - s_{min})}{2 - (s_{max} + s_{min})}}{\frac{M_{max} + M_{min}}{2}}. \quad (16')$$

The emphasized conditions being satisfied, it is ensured the accomplishment in good conditions of the deformation mechanical work prescribed for a press which have the flywheel and the electric engine rationally established, according with the requirements mentioned in the paper.

For the determination of the conditions they are taken into consideration the kinematics characteristics stipulated at the press designing by the working angle ϕ_l, the crank rotational angle corresponding with the period when the retrieve of the kinetic energy yielded by the flywheel ϕ_r, the medium angular velocity of the motor crank ω_{med} corresponding to the number of double strokes per minute n_{cd}, the characteristics of the adopted electric engine by parameters as maximum moment M_{max}, minimum torque M_{min} and their specific maximum slip s_{max} and respectively minimum slip s_{min}.

The value of the mechanical deformation work is determined by the maximum deformation force and the maximum preview deformation lift for which the ϕ_l has been determined.

For the determination of the specific mechanical work accordingly to the accomplishment of the different tasks, it can be used one of the next relationships:

$$L_D = F_m \cdot s_D = k_D \cdot F_D \cdot s_D, \quad (17)$$

$$L_D = M_m \cdot \phi_D = k_D \cdot M_D \cdot \phi_D, \quad (17')$$

where: k_D is representing the coefficient whose value is established depending on the ratio between the medium force and the effective deformation force or according with the correspondent torques ratio determined by this forces. Some examples are: k_D = 0.63 for punching and drawing [1–3]; k_D = 0.32 for cold bending [1–3]; F_D – the necessary maximum force for the accomplishing of the deformation task; F_m – the medium value of the deformation force; $s_D = h_l$ – the maximum deformation stroke stipulated to be achieved by the mechanisms of the press; M_D – the maximum resulting moment of the forces system which is actuates over the mechanism of the press by respect at the crankshaft level; M_m – the medium resulting moment of the forces system which is actuates over the mechanism of the press by respect at the crankshaft level; ϕ_D – the crank angle is corresponding to the maximum deformation stroke stipulated to be fulfilled by the press mechanism.

10. CONCLUSION

The elaborated study emphasizes the fact that the limits variation of the driving electric engine speed the on its mechanical characteristic over the admissible irregularity at press running.

Also, it comes out that the better solutions are given by the engine with higher slip, that allows the use of a greater flywheel irregularity and a reducing of the flywheel mass.

At the establishing of the irregularity it is required to take into consideration the influence of the medium speed at witch the system is working because this determines mostly the value of the kinetic energy yield by the flywheel.

It will be taken into consideration the fact that the angular values corresponding to the working cycle for which the flywheel choice will be done, to be specific for the nominal working conditions of the press.

This means that at the calculation it will be taking into account the maximum deformation stroke stipulated at the press running. On basis of it they will be determined the resulted angles for the other phases of the working cycle.

Also, for the determination of maximum moment and minimum moment values they must be taken into consideration the resulted values at the maximum deformation force and at maximum working stroke.

These values must be according to the functional characteristics of the adopted electric motor.

From this point of view it is required to take into consideration the correlation between the maximum slip and the minimum slip of the adopted electric motor and the irregularity prescribed at the flywheel running (relation 10).

The determinations will be done by taking into consideration the press running in automatic regime (repeated working strokes) with taking into account the fact that for this regime it results the maximum loading for the driving electric motor.

It is recommended that after the adoption of the flywheel and the accomplishment of its form and dimensions to achieve verification of the running conditions under the loading of the assembly.

This means to fulfill the loading characteristic of the electric motor during the running cycle of the press.

To accomplish a working concordance between the flywheel system elements it will be taken into account the determination of the flywheel reduced moment of gyration as been achieved by the totality of kinematics elements masses and their correspondent speeds.

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