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Study of the working body mechanism in forging-and-stamping equipment*

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Изучение механизма рабочего органа в кузнечно-штамповочном оборудовании***

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Введение. Статья посвящена исследованию синтезированной принципиальной схемы фрикционного контакта твердых тел в кузнечно-штамповочных машинах. Установлена возможность получения максимума нагрузочной характеристики фрикционного контакта внутри интервала изменения коэффициента трения. Выявлены две следующие возможности сил трения фрикционного контакта: на границах указанного интервала они будут равны при наличии максимума равенства; при данных условиях они достигают наибольшей стабильности.

Материалы и методы. При изменении величины угла меняется положение точки максимума. Это приводит к нарушению равенства сил трения на границах интервала изменения коэффициента трения. В таком случае коэффициент точности должен определяться отношением максимума функции к наименьшему граничному значению. Для этого необходимо установить тенденции изменения граничных значений функции, связанные с варьированием величины угла. Для решения этой задачи новую величину тангенса угла давления представили в виде произведения коэффициента варьирования на базовое значение тангенса угла.

Результаты исследования. Полученные результаты показывают высокую стабильность силы трения при проскальзывании тел фрикционного контакта (ФК). Однако при больших величинах угла давления чувствительных элементов датчика-преобразователя максимальная сила трения кратковременно может быть пропорциональна текущему значению коэффициента трения.

Обсуждение и заключения. Модернизированная принципиальная схема ФК позволяет теоретически получить очень высокую стабильность силы трения. ФК не должен обращаться в ноль в интервале изменения коэффициента трения выходного параметра основной фрикционной группы (ОФГ) и при наличии максимума функции нагрузочной способности ФК. Необходимым условием этого является передача чувствительными элементами дополнительной фрикционной группы (ДФГ) ее полной нагрузки.

Introduction. The synthesized basic diagram of the frictional contact of solids in forging-and-stamping machines is considered. The possibility of obtaining the maximum load characteristics of the frictional contact within the variation interval of the friction factor is determined. The following two possibilities of frictional contact forces are indicated: they will be equal at the boundaries of the specified interval if there is maximum balance; they achieve the greatest stability under these conditions.

Materials and Methods. When the angle value changes, the position of the maximum point changes. This causes violation of the friction forces balance at the boundaries of the variation interval of the friction factor. In this case, the accuracy coefficient should be determined by the ratio of the maximum of function to the least boundary value. Doing this requires establishing trends of changing the boundary function values associated with the angle variation. To solve this problem, a new value of the pressure angle tangent was presented as a product of the coefficient of variation by the base value of the angle tangent.

Research Results. The results show high stability of the friction force under slipping of the frictional contact (FC) bodies. However, at large values of the pressure angle of sensing elements of the transducer, the maximum friction force can be for a short moment proportional to the current value of the friction factor.

Discussion and Conclusions. The upgraded FC basic diagram enables to theoretically obtain very high stability of the friction force. The FC should not vanish within the variation interval of the friction factor of the output parameter of the basic friction group (BFG) and at the maximum of function of the FC load capacity. A necessary condition for that is the transfer of full capacity of the additional friction group (AFG) by the sensing elements.

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Introduction. The synthesized schematic diagram of frictional contact (FC) of solids in forging-and-stamping machines is considered. The analysis shows the possibility of obtaining maximum load FC characteristics within the variation interval of the friction factor. The following two possibilities of frictional contact forces are identified: they will be equal at the boundaries of the specified interval if there is maximum balance; they achieve the greatest stability under these conditions. The results obtained show high stability of the friction force during slipping of FC bodies. However, at large values of the pressure angle of the sensitive elements of the transducer sensor, the maximum friction force can be briefly proportional to the current value of the friction factor.

Materials and Methods. The FC scheme shown in Fig. 1 is free from this disadvantage.

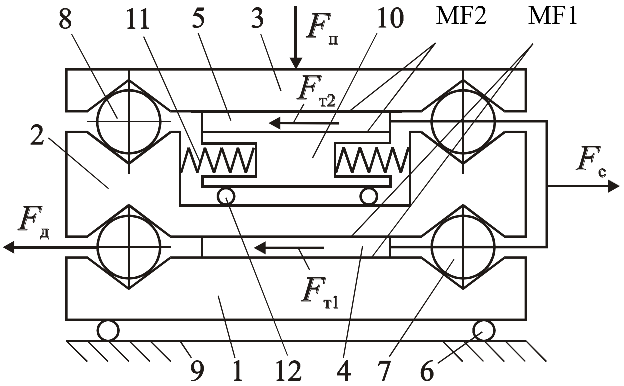

Fig. 1. Basic diagram of frictional contact

The master friction group (MF1) includes bodies 1, 2 and 4; the additional friction group (MF2) contains bodies 3, 5 and 10. Between 1 and 2, 2 and 3 bodies, sensitive elements in the form of rolling bodies 7 and 8 are placed in the profiled sockets.

The difference of the considered scheme is the division of body 2 into two parts, due to which the connection between bodies 2 and 5 is carried out using body 10 interacting with body 2 through the springs 11. This allows transferring half of the total load of MF2 from body 2 directly to the rolling elements 8 making them a leading element in the MF2. The second half of the total load of MF2 is transmitted through the springs 11 from body 2 to body 10, and further through friction – to body 5. In addition, the place of $F_Д$ moving force is transferred from body 1 to the rolling elements 7. These differences allow excluding the impact of the pressure rolling 7 on the load distribution between the friction surfaces in MF1 and MF2 when the friction factor value changes [1].

To restrict to the linear nature of the friction between the bodies 1 and the supporting surface 9, as well as between the bodies 2 and 10, the rollers 6 and 12 are installed.

The formula for determining the value of the FC friction force depending on the disturbance input is as follows (at the same values of the feedback gain factor of MF1 and MF2]:

$$\sum F_Т = \frac{4F_П f}{(1+f\text{tg}\alpha)^2}, \quad (1)$$

where $\sum F_Т$ is total ultimate friction force between bodies 1, 2, 4 and 3, 5, 10; ; $F_П$ is initial clamp force of friction couples; f is current value of the friction factor between the mentioned bodies; α is pressure angle between rolling elements 7, 8 and the socket.

It was also established that the function (1) within $f_{\min}...f_{\max}$ range of values does not have a maximum since the friction force of MF1 vanishes at the value of the friction factor of $f_0 = 1/\text{tg}\alpha$. (Here, $f_{\min}$ and $f_{\max}$ are, respectively, the smallest and largest values that the friction factor can take in actual FC operating conditions for the adopted combination of materials of friction couples.) The same value corresponds to the imaginary maximum of the function

(1) since in $f_{\text{o}} ... f_{\max}$ interval, the FC load is transferred through MF2friction group, the friction force of which increases with f growth. This does not ensure the FC friction force stability despite the fact that it is somewhat higher than that of the first-generation FC (at values $f_{\min} = 0.1$, $f_{\max} = 0.8$ and $\text{tg}\alpha = 1.125$, the accuracy coefficient is equal to $K_{\text{т}} = 2.5$ and $K_{\text{т}} = 3.67$).

The real maximum of the FC load characteristics within the variation interval of the disturbance input is possible through modifying MF2 according to the scheme (see Fig. 1). This modification is to reduce the number of friction couples. To this end, it is necessary to exclude elements 10, 11 from the scheme and to rest body 5 directly upon body 2 through the rollers 12.

In accordance with this, we find:

$$F_{\text{т}2} = (F_{\text{п}} - F_{\text{p}2}) f ,$$

where $F_{\text{т}2}$ is friction force of MF2; $F_{\text{p}2}$ is control action of MF2 (expansion force on the rolling elements 8).

But

$$F_{\text{p}2} = F_{\text{т}2} \text{tg}\alpha ,$$

hence,

$$F_{\text{т}2} = \frac{F_{\text{п}} f}{1 + f \text{tg}\alpha} . \quad (2)$$

Friction force between MF1 pairs is equal to:

$$F_{\text{т}1} = 2\left[F_{\text{п}} - \left(\frac{F_{\text{т}1}}{2} + F_{\text{т}2} \right) \text{tg}\alpha \right] f .$$

Considering the relation (2), we find

$$F_{\text{т}1} = 2F_{\text{п}} \frac{f}{(1 + f \text{tg}\alpha)^2} . \quad (3)$$

The relation (3) does not contain the difference in the numerator; therefore, this function does not vanish on any conditions. It only asymptotically approaches zero under the following conditions:

- theoretically unlimited increase in friction factor;
- a maximum at the point corresponding to $f_{\text{к}} = 1/\text{tg}\alpha$ value [2–5].

Summing up the friction forces in the relations (2) and (3), we obtain

$$\sum F_{\text{т}} = F_{\text{п}} f \frac{3 + f \text{tg}\alpha}{(1 + f \text{tg}\alpha)^2} . \quad (4)$$

Differentiating the function (4) by f argument and equating the derivative to zero, we find the value of the friction factor corresponding to a maximum of the function:

$$f_{\text{к}}' = \frac{3}{\text{tg}\alpha} . \quad (5)$$

Substituting in sequence $f_{\min}$, $f_{\max}$ values in the expression (4), and equating the obtained relations to each other, we find:

$$\text{tg}\alpha = \frac{(m+1) + \sqrt{(m+1)^2 + 12m}}{2 f_{\max}} . \quad (6)$$

Here, m is relative width of the friction factor interval: $m = f_{\max} / f_{\min}$.

At the found $\text{tg}\alpha$ value, the function (6), having a maximum at the point corresponding to the value (5), takes the same values at the boundaries of the variation interval of the friction factor.

In this case, the coefficient of accuracy is determined by the ratio of a maximum of the function (4) to its any boundary value (for $f_{\min}$ or $f_{\max}$ values). Based on this, we get:

$$K_{\text{т}} = \frac{9(1 + f_{\max} \text{tg}\alpha)^2}{8 f_{\max} \text{tg}\alpha (3 + f_{\max} \text{tg}\alpha)} . \quad (7)$$

Set the value of parameter ($\text{tg}\alpha$) at which $K_{\text{т}}$ value is minimal. When $\text{tg}\alpha$ value changes, the position of the maximum point ($f_{\text{к}}'$) changes as well. Only the relation (6) establishes the equality of the friction forces on the boundaries of the variation interval, therefore, changing the position of the maximum point of the function (4) violates the above equality.

In this case, the accuracy coefficient should be determined by the ratio of a maximum of the function (4) to the smallest boundary value. To do this, it is required to establish trends in the boundary values of the function (4) associated with $\text{tg}\alpha$ value variation [6 –10].

To solve this problem, let us present a new value of the pressure tangent as a product of K variation coefficient and the base value of the tangent angle in accordance with the expression (6), i.e.:

$$\text{tg}\alpha_i = K\text{tg}\alpha . \qquad (8)$$

Based on this, we can write considering (4):

$$\frac{(3m + Kf_{\max}\text{tg}\alpha)f_{\max}}{(m+Kf_{\max}\text{tg}\alpha)^2} > \frac{(3+Kf_{\max}\text{tg}\alpha)f_{\max}}{(1+Kf_{\max}\text{tg}\alpha)^2} .$$

Here, the left side corresponds to the FC friction force at $f = f_{\min}$, and the right side – to the friction force at $f = f_{\max}$. The solution to the latter inequality with respect to the coefficient of variation is:

$$K \in \left(-\infty; \quad \frac{(m+1) - \sqrt{(m+1)^2 + 12m}}{2f_{\max}\text{tg}\alpha} \right) \cup (1; \quad +\infty) .$$

Since $\text{tg}\alpha > 0$, the fraction in parentheses of the left side of the solution is negative, therefore, for $K > 1$, the resulting inequality is undoubtedly fulfilled, i.e. when $f'_{\text{к}}$ maximum point is shifted to smaller values, to calculate the accuracy coefficient, it is necessary to use the value of the FC friction force corresponding to $f_{\max}$ value and conversely, when $1 > K > 0$, it is necessary to take the friction force value corresponding to $f_{\min}$ value [11–13].

Using this conclusion, we make the inequality of $K_{\text{T}1} > K_{\text{T}}$ form where $K_{\text{T}1}$ is the accuracy coefficient calculated with consideration of the equality (8). We have:

$$\frac{(1 + Kf_{\max}\text{tg}\alpha)^2}{K(3+Kf_{\max}\text{tg}\alpha)} > \frac{(1+f_{\max}\text{tg}\alpha)^2}{3 + f_{\max}\text{tg}\alpha} .$$

The inequality is set up given that $K > 1$.

Transformation of the resulting inequality to the form

$$3 + (1 + K)f_{\max}\text{tg}\alpha + Kf^2{}_{\max}\text{tg}^2\alpha > 0$$

shows the validity of the assumption that $K_{\text{T}1} > K_{\text{T}}$.

We investigate the ratio of the values of the coefficients of accuracy when the maximum point of the function (4) is shifted to the region of large values, that is, at $K < 1$. Then, $K_{\text{T}2} > K_{\text{T}}$ or

$$\frac{(m + Kf_{\max}\text{tg}\alpha)^2}{K(3m+Kf_{\max}\text{tg}\alpha)} > \frac{(1+f_{\max}\text{tg}\alpha)^2}{3 + f_{\max}\text{tg}\alpha} .$$

Transformation of the resulting inequality to the form

$$3m + (m + K)f_{\max}\text{tg}\alpha - Kf^2{}_{\max}\text{tg}^2\alpha > 0$$

and the solution of the latter give

$$K < \frac{m(3+f_{\max}\text{tg}\alpha)}{(f_{\max}\text{tg}\alpha - 1)f_{\max}\text{tg}\alpha} .$$

The fraction on the right side of the obtained solution is equal to one at the value

$$\text{tg}\alpha = \frac{(m+1)+\sqrt{(m+1)^2+12m}}{2f_{\max}} ,$$

which fully corresponds to the solution (6). Therefore, the inequality $K_{\text{T}2} > K_{\text{T}}$ is performed if $K < 1$.

Research Results. Let us take the final judgment on the stability of the FC friction force for various forms of load characteristics. For this purpose, we determine the FC accuracy coefficient when the function (4) has a maximum at $f = f_{\max}$. In this case, the function monotonically increases in the range of the friction factor variation. At that, $f_{\max} = 3 / \text{tg}\alpha$ equality is true. We will get:

$$K_{\text{T}3} = \frac{\sum F_{\text{T}(f_{\max})}}{\sum F_{\text{T}(f_{\min})}} = \frac{(m + 3)^2}{8(m + 1)} .$$

Considering $K_{т3} > K_{т}$, we will find:

$$3m(3 - mf_{max}\,\text{tg}\alpha) + m(3 - m)f^{2}_{max}\,\text{tg}^2\alpha + 9(1 - f_{max}\,\text{tg}\alpha) < 0.$$

For all friction materials used as FC friction couples, $m > 3$. According to (6), $f_{max}\,\text{tg}\alpha > 1$, therefore, it is obvious that the differences in the brackets of the obtained inequality are negative and the above assumption is true.

Thus, the analysis performed shows that the greatest stability of the FC output parameter is in the case when the function (4) has a maximum within the interval of the friction factor variation and takes the same values at its boundaries.

When $m = 8$ and $f_{max} = 0.8$, we get $\text{tg}\alpha \approx 14$. Then, $f'_{к} \approx 0.214$. In this case, maximum of the function (3) will be at $f_{к} \approx 0.071$ which is almost identical to the lower boundary of the interval $f = f_{min} = 0.1$. The function (3) decreases within the interval of the friction factor variation. With such initial parameters, $K_{т} \approx 1.04$ and $K_{т3} \approx 1.68$.

Discussion and Conclusions. As is obvious, the modified FC block diagram enables theoretically to obtain very high stability of the friction force. However, due to the relatively large value of $\text{tg}\alpha$ parameter, $F_{п}$ force is used inefficiently. The FC should not vanish in the variation interval of the friction factor of the output parameter of the master friction group (MFG) and in the presence of maximum of the function of the FC load capacity.

A necessary condition for this is the transfer of full load of the MFG by the sensitive elements of the additional friction group (FGD). An additional condition for the existence of a maximum can be formulated as follows: with an equal number of friction couples of both friction groups, the MFG sensitive elements transfer part of its full load; with a smaller number of friction couples than in the AFG, the sensitive elements transfer the full load of the MFG.

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