PIPE AND TUBE PRODUCTION

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SOME DISTINCTIVE FEATURES OF PIERCING PROCESS ON A CROSS-ROLL PIERCER

The authors considered tubular mill cross roll piercer drive line dynamics with consideration of the revolute joint shafts and work roll installation mechanism behavior distinctive features. The scientists made the cross-roll piercer main drive line differential equation and stated its computational solution. The authors considered the accommodated three-mass behavior pattern of the system and received the solution of the problem with using the software product Solid Works IT Simulation X. So the authors of this article defined the basic conditions for unstable dynamic phenomena to occur in drive line and the cross-roll piercer work roll installation mechanism. It was shown that unstable system dynamics is one of the main reasons why mismatches of the results of the known theoretical investigational study and ultrasonic thickness measurements of the tubes on the cross-roll piercers of the tubular mill 350 occur. The scientists found the main reasons why the parametric vibrations occur in the drive cage of cross-roll piercer is that the cross-roll piercer work roll installation mechanism occurs due to the wall thickness variation generation. The authors determined spheres of the system functioning stability zone depending on operating regimes and the cross angle of the work roll with considering the spatial position of the shaft facility position. The authors of the article also determined the necessary and sufficient stable conditions of solidary stable functioning of the elements in the cross-roll piercer drive line. In case if it is necessary to stabilize the piercing processes the authors offered the plan of the main drive shaft refreshment and of the cross-roll piercer work roll installation mechanism №1 of tubular mill 350.

Key words: piercing, billet, rolling mill, tube, rate oscillation, wall variation, dynamics, drive, roll, oscillations, shaft, gimbal, revolute joints, moment of inertia, stiffness, block, installation mechanism, withstandability

Introduction. Increase of the modern tubular mills productivity is being restrained by the cross-roll piercers tubular billet piercing speed and the power ranges level.

The tubular billet piercing regimes on the heavy duty tubular mills cross-roll piercers are multifactorial complex tasks of interaction between the piercing processes and the machine for its implementation [1, 2]. In the world and national practice of seamless tubes production they tried to increase the screw-rolling mill drives work rate many times. It should be noted that at the same time these processes, as a rule, are followed by not only significant transient loads, but also noticeable withstandability reduction in the tubular billet piercing process [3].

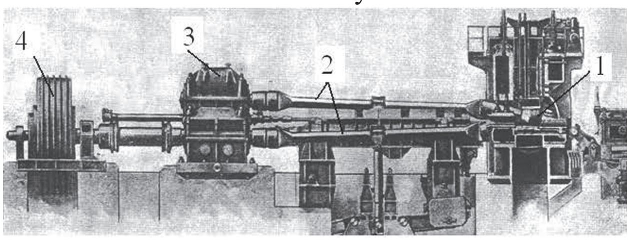
The numerous researches of the cross-roll piercers dynamics in most cases, as a rule, do not consider the transmission line graded structure effect and change of the work rolls cross angle on the piercing processes. Some significant scientific works in this course are generalized and presented in [3].

In view of the above, conduct of the researches, focused on choice of efficient tubular billet piercing regimes by stabilizing the heavy-duty the tubular mills cross-roll piercers drive line dynamic response, is currently central as of now.

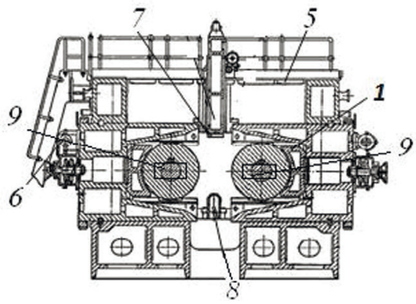
Research objective. In order to install one of the pierced shells wall variation mechanisms and the mill main drive line effect on the piercing process we will perform the preliminary functioning distinctive features analysis and consider this mechanical system construction.

The rolling tube screw-rolling mill drive cage includes the electric motor 4 with the main clutch, pinion cage reducing gear 3, multifaceted telescopic spindles 2 based on stationary gimbal joints and work rolls 1, installed in two barrels 9 the rolls installation mechanism 6 c and the mill housing 5 with two colt holders 7 and 8 (Fig.1 a) [1, 2].

It should be noted that flexible fixing of the work rolls within the installed cross angle in the existing plan of their assembly in the work cage is impossible. At the same time there is a probability that some large oscillations are actuated along all the main drive transmission circuit. Some conditions occur during the synchronizing turn and when the barrels with the rolls are running against each other. The torsional oscillations in the work rolls turn circuit are generated mostly by the powers ratio change of correspondingly in the shaft joints and the work rolls bearing supports, and this causes significant transient loads. Angular rotation rate of the actuators possesses certain level of induced non-uniformity, as in the work rolls drive there is the shaft based on the gimbal gear [3]. It is well known that change of the piercing rate depends on change of the component of relative speed and tilt angle of the work roll. It should be noted that when we implement engineering process of the tubular billet piercing, resistance force makes periodic alterations harmonically, and consequently reaching maximum and minimum value alternately.



a)



b)

c)

Fig. 1. The main drive a) the cage b) and destroyed the tubular mill 350cross-roll piercer No1 shaft

However, the work roll and its drive of turn in the barrel on the required cross angle go through the alternate moment from dynamic and axis components of the resistance force. Under effect of such forces and resistance ones the periodic quantity of angular drive rate and correspondingly the work roll cross angle in the barrels.

In order to research the work rolls stroke non-uniformity effect on the piercing processes we conduct wall thickness test (measure of lateral and longitudinal wall variation) "rejected" from the tubular blooms streaming after first and second cross-roll piercers of the tubular mill 350 (billet steel 13HMF, the billet with diameter 250mm, complete tube is 325x15,9mm). The tubular blooms wall thickness processing results, which we received after the cross-roll piercer No.1 of the tubular mill 350 are on the Fig. 2 (the data of LLC "INTERPIPE NIKO TUBE") [2, 10].

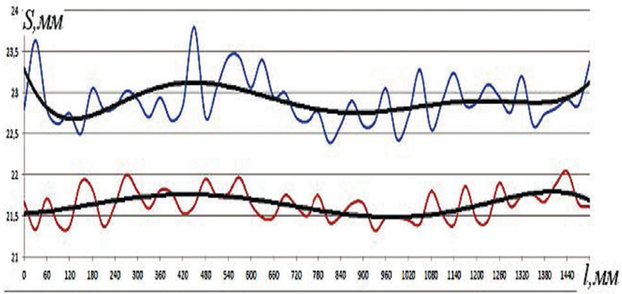


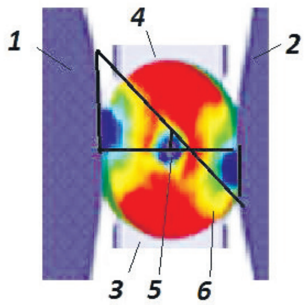
Fig. 2. Wall thickness (longitudinal wall variation) of the tubular blooms template after the tubular mill 350 cross-roll piercer (billet steel HMF, diameter 250 mm – the complete tube 325x15,9mm)

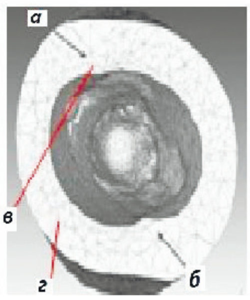
The wall thickness test results analysis shows that the nature of the tubular blooms wall variation distribution is compatible with non-uniformity parameters of the work rolls stroke on the appropriate tubular mill 350 cross-roll piercers.

The results of wall thickness test show the unstable periodic nature of the parametric phenomena in the drive line and some reasons why non-uniformity occurs during the work rolls stroke on the tubular mill 350 cross-roll piercer No1.

Due to harmonic distortion and the work rolls speed differential ($V_1 \neq V_2$) in the area they interact with the billet pierced with the internal tool and shoes, thanks to which the orientation of the speeds centre ΔV in a sign-variable manner moves up and down in vertical plane of the working zone, pressing the tubular bloom to the shoes makes the appropriate hollow a, b, c and d in the corpus of the tubular bloom (Fig. 3a). This causes impairment of the real working zone and negative stability, when the primary wall of the tubular bloom is generated, is one of the reasons why the induced wall variation occurs.

Problem-solving procedure. Now in the first place we are proceeding to research of the cross-roll piercer drive line dynamics effect on the tubular billet piercing process. It is natural that change of the work rolls cross-angle is determined correspondingly with the system masses moment of inertia and the torsional stiffness of the rolls turn line in the barrels in the cage. At the same time it is necessary and enough to check performance conditions of all the mechanical system drift from the parametric resonance. However, in the first approach the value of the rolls critical angular rate and barrel installation mechanism parametric oscillations frequency with the rolls should follow the condition of the drift from the resonance. Accordingly, the moment of inertia with the system masses moment of inertia and the torsional stiffness of the rolls turn line in the barrels in the cage and angular rate of the transmission movement with the cross-roll piercer drive line shaft unit should differ.



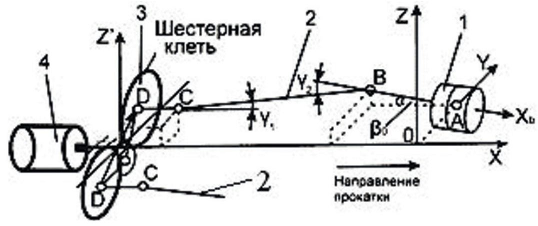


a) b)

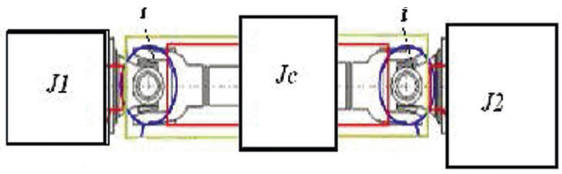
Fig. 3. Nature of the rates distribution on the effective work rolls radiuses a) and generation of the hollows in the working zone during the tubular mill piercing b): 1, 2 – the work rolls; 3 , 4– the shoes; 5 – the internal tool; 6 – the tubular bloom

It should be noted that the axis of the work roll barrel during the tubular mill piercing definitely performs some harmonic oscillations. Upon that the angular rate vector is perpendicular to the rolling axis. The gyroscopic moment of the force couple, occurring in the plane, perpendicular to the angular rate of the roll axis turn, causes metal pressure cycling on the work rolls and cross-roll piercer drive line torque. Therefore, in the course of engineering process the main drive, besides the common (quasi-static) resistance to metal deformation $M\tilde{n}$, goes through resistance forces moment which depends on angular rate (according to the way it occurs), which corresponds to gyroscopic moment δM of the work rolls. Consequently, if the considered system perturbation period coincides with the main drive angular rate change period, then in big amplitude of the work rolls gyroscopic moment, sufficient to overcome the friction forces moment in the turn drive circuit, it builds up periodically.

Using the methods [5, 9] let us proceed to making the tubular mill cross-roll piercer drive line three-mass transient model motion differential equations.



a)



б)

Fig. 4. Diagram of the tubular mill cross-roll piercer main drive with possible elements offsetting from the design positions a) and adapted mechanical system three-mass transient model b)

The equations for the chosen tubular mill cross-roll piercer drive line three-mass model movement (Fig. 4 b) contain typical drive perturbations (right parts) with frequency, coinciding with frequency of the equation left part periodic coefficients, which has an effect of the determining value on the occurred unstable decision, arising with course of time. This, in its turn, causes breach of tubular billet piercing process stability. In this case the differential equations of rotational motion for the cross-roll piercer drive line elements three-mass model, containing the shaft unit of the graded structure take the form of:

$$\begin{cases} (I_{01}+I_1 i^2)\dfrac{d^2\varphi_1}{dt^2}+I_1 i\dfrac{di}{d\phi}\left(\dfrac{d\varphi_1}{dt}\right)^2+\tilde{n}_{12}(\varphi_1-\varphi_2)=M_{d1}-M_{c1}-\delta M_1\, i; \\ \tilde{n}_c\dfrac{d^2\varphi_c}{dt^2}-{}_{12}(\tilde{\varphi}_1-\varphi_c)+{}_{23}(\varphi_c-\varphi_3)=0; \\ (I_{02}+I_2 i^2)\dfrac{d^2\varphi_2}{dt^2}+I_2 i\dfrac{di}{d\phi}\left(\dfrac{d\varphi_2}{dt}\right)^2-\tilde{n}_{23}(\varphi_c-\varphi_3)=M_{d2}-M_{c2}-\delta M_2\, i, \end{cases} \quad (1)$$

where φ_1, φ_c and φ_2 are the mass torsion angles during oscillations; I_{01} and I_{02} are brought to the drive shaft of the inertia moment in the drive sides masses; I_c – shaft unit moment of inertia;, I_1, I_2 – respectively – the work rolls inertia moments, brought to the idle shaft of the drive; $\tilde{n}_{12}$ and $\tilde{n}_{23}$ are the stiffnesses of the transmission elements; M_{d1} and M_{d2} is the driving torque of the main drive, linearly dependent on angular rate $\omega(t)=\frac{d\varphi}{dt}$; M_{c1} and M_{c2} are the engineering resistance forces torques; δM_1 and δM_1 are the gyroscopic moments from turn of the barrels with the rolls; i is the gearing ratio of the shaft unit structure.

The shaft unit main drive dimensional gimbal drive gearing ratio, according to [3, 6], is determined as:

$$i = AB\left(1+tg^2(\varphi)\right)\Big/\left[A^2tg^2(\varphi)+(B+Ctg^2(\varphi))^2\right], \qquad (2)$$

where $A=\cos(\gamma_2)\left[1+tg^2(\theta_ø-\delta_ð)\right]$;

$B=\cos(\gamma_1)\left[1+tg^2(\theta_ø-\delta_ð)\cos^2(\gamma_2)\right]$;

$C=\sin^2(\gamma_2)\,tg(\theta_ø-\delta_ð)$.

Here γ_1, γ_2 is angle between the drive shaft and intermediate one and angle between the intermediate and idle one correspondingly, $\gamma_j \leq Ð\,°, j=1,2$; $\theta_ø$ is the angle, to which second fork of intermediate shaft is displaced to the first one to the shaft rotation side; $\delta_ð$ is the angle, to which the idle shaft is deviated from the plane, brought through the drive and intermediate shafts.

Considering the increasing order of ratios $\grave{A}, \hat{A}, \tilde{N}$, we can accept:

$\grave{A}=1+\varepsilon_1$, $B=1+\varepsilon_2$, $C=\varepsilon_3$, *where* ε_j *<1*, *j*=1, 2, 3.

Upon that we can simplify the expression (3) and represent as:

$$i=1-(\varepsilon_1+\varepsilon_2)+(\varepsilon_1-\varepsilon_2)\cos(2\varphi)+\varepsilon_3\sin(2\varphi). \qquad (3)$$

The driving torque of the cross-roll piercer drive line is mainly determined by natural torque-vs-displacement curve of the main drive electric motor [5, 7].

After replacements and transformations, the equation (1) is brought to the following parametric form. The differential equations of the work rolls drive line drive motion in this case are definitely different from the known Mathieu parametric equation [6, 8], as the periodic coefficients are not small. The numerical differential equation system growing (1) in setting basic problem Cauchy along with using the standard software package by means of mathematic simulation allows to find out some main reasons why the parametric oscillations of the work roll axis occur and, in their turn, significantly effect on the tubular billet piercing processes on the cross-roll piercer in Fig. 5).

Analysis of the received results shows that the parametric oscillations, which occur in this process, are the main reason of mismatch between the results of the experimental and the known experimental studies [3] of the cross-roll piercers. At the same time it should be noted that thanks to the differential equations of the torque-vs-displacement curve mass motion, the roll turn circuit in the barrels and other elements of the cage due to availability of periodic component of the reaction force in the assemblies have harmonic coefficients, then the system has certain alternating areas of parametric stability of the system.

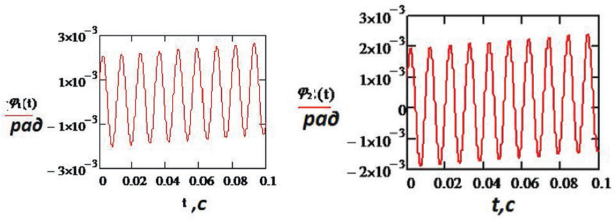


Fig. 5. Dynamics of the tubular mill 350 cross-roll piercer drive line No 1 ((billet steel 13HMF, diameter 250 m – complete tube 325x15,9mm) n=60rot/min)

In order to perform comparative analysis of the primary torque-vs-displacement curve transient models, let us proceed to researching the transient model of the tubular mill cross-roll piercer work rolls drive line along with using IT technologies. In order to research the dynamics of the cross-roll piercer drive line let us use the software product Solid Works IT Simulation X. the model of the main drive of the tubular mill cross-roll piercer work rolls with multifaceted shafts like "drive shaft" is represented as some simplified analytical model in form of three masses J_1; J_c and J_2 which are connected with each other by elastic linkages c_{12} and c_{23} and damping elements b_1 and b_2 (Fig. 6).

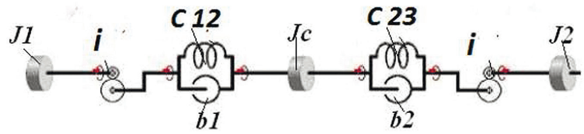


Fig. 6. Adaptive and transient model of the tubular mill cross-roll piercer work rolls shafts like "drive shaft" (as illustrated by Cardan Shaft)

The transmitting elements of the shaft joints reflect non-uniformity of the course in connections of the cross-roll piercer main drive elements. With taking the accepted conditions into consideration, the cross-roll piercer work rolls drive is simulated by the appropriate inertia member, the assembling units like "damper spring" and the transmitting elements of the shaft joints of the graded structure.

Now we are generating the initial data for research, choosing the example of calculation of the work rolls main drive with the tubular mill 350 cross-roll piercer multifaceted shafts. In order to study the work rolls main drive with the tubular mill 350 cross-roll piercer multifaceted shafts the initial data are generated in accordance with requirements of the transient model "drive shaft" installed into the software product Solid Works IT Simulation X. The results, which we received after numeric computation, are as follows: the nature of change angular movement of the drive shaft, angular rate of the drive shaft, angular acceleration of the drive shaft and torque in the place of the main drive shaft drive shaft connection with the tubular mill 350 cross-roll piercer work rolls.

The stable functioning parameters of both the drive line elements and the tubular mill cross-roll piercer work rolls in this case are determined on the basis of the known parametric withstand ability mathematical theory premises and asymptotic methods of the differential equations researching (1). Depending on the operation regimes of the cross-roll piercers, the cross-angle and spatial arrangement of the main transmission shaft unit elements from the differential equation system values (1) we can define the areas of the system parametric withstand ability. For instance, during the tube piercing from the billets of diameter 250 mm on the tubular mill 350 cross-roll piercer No1, considering the required upgrade of the main drive equipment and the cage, in terms of the work rolls cross-angle engineering process installation is provided 10°30'…12°30'.

It is convenient to assess the tubular mill 350 cross-roll piercer No1 dynamic state based on the work rolls drive three-mass model research by building the mechanical system amplitude-frequency response. In order to collate the received results, we compare the behavior of virtual prototype with tubular mill cross-roll piercer driveline analytical model with the multifaceted shafts like "drive shaft". The results, we received, show, that the accepted models of the tubular mill cross-roll piercer driveline are accurate.

If we use the recommended values of the cross-angle (9°30'…12°30') and the corresponding main drive rotation frequencies (60…120 rot/min) on the tubular mill 350 cross-roll piercer No1 we can achieve significant reduction of the mechanical system rolls stroke non-uniformity level and the dynamic processes level, which leads to the tubular blooms quality increase. In this case, at the same time we can observe decrease in level of the driveline elements dynamics and all the tubular mill cross-roll piercer No1 basic mechanisms.

The experimental study of the tubular mill 350 cross-roll piercer No1 work rolls stroke by means of the encoders (resolvers), installed on their axes and the unit-record equipment based on automatic digital transducer, are represented on the Fig. 7.

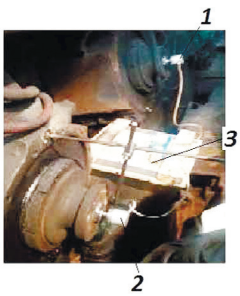


Fig. 7. Measurements of the tubular mill 350 cross-roll piercer No1 work rolls stroke; 1, 2 are the encoders (resolvers), installed on the axes of the work rolls, 3 – unit-record equipment based on automatic digital transducer

The results of the tubular mill 350 cross-roll piercer No1 work rolls angular rates processing are represented on the oscillograph trace (Fig.8).

In Fig. 8 we can see that the tubular mill 350 cross-roll piercer No1 work rolls angular rates are of alternating nature and significantly differ by both amplitudes and phases. This phenomenon leads to non-uniformity of distribution rates field in all the working zone during the tubular billet piercing and the induced tubular bloom wall variation generation [2, 10].

According to experimental studies and typical conditions of tubular mill 350 cross-roll piercer No1, cage functioning we found that the cross-angle of the work rolls is efficient to withstand within 9°30'…10°30'.

It should be noted that in the future work rolls cross-angles increase and drive line rotation frequency increase it is necessary to implement additional measures (for example, using structure of the shafts with opportunity to adjust the gearing ratio) on stabilizing the "drive line – work roll – tubular billet" heavy-duty mechanical system dynamics level. The experience in operation of the two tubular mill 350 cross-roll piercers proves that it is necessary to install and further reliably fixture the work rolls with the barrels in the mill housing windows within the required value of the cross-roll piercer by corresponding mechanisms.

Adjusting of the cross-roll piercer No1 cage rolls drive rotation non-uniformity is performed by upgrading the pin-and-eye connection collapsible multifaceted shafts from the side of the work rolls. The mills shafts pin-and-eye connections are performed in form of removable elements, namely half-coupling and the forks with the castellate indents on the flanks, which have the opportunity of incremental turn with respect to one another (Fig. 9).

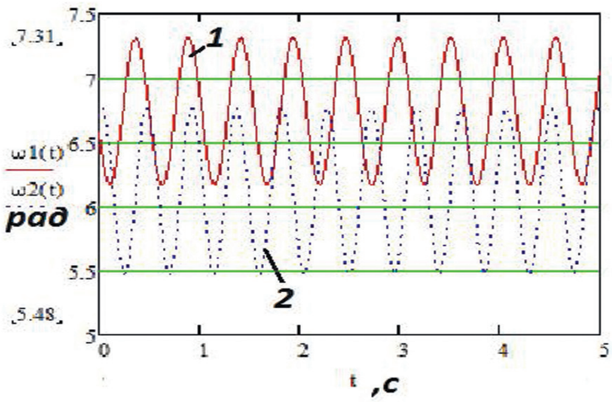


Fig. 8. The oscillograph trace of the tubular mill 350 cross-roll piercer No1 work rolls angular rates: 1 – angular rate of the first roll; 2 – angular rate of the second rolls

It should be noted that not from the side of the drive the cross-roll piercer work rolls are equipped with corresponding angular rate sensors like tachometer generation or more up-to-date sensors (encoders) (resolvers) (Fig. 7).

After upgrading of the mechanical system of tuning control of self-standing tubular mill cross-roll piercer cage rolls drive working stroke is performed as follows: on non-working stroke of the cross-roll piercer (without the tubular billet) a record of the corresponding rolls rotation angular rate is being performed. When we find disregistry in the angular rates of the rolls rotation we perform adjustment of the cross-roll piercer main drive stroke by the revolute joints forks incremental turn of one of the shafts in the course of rotation to the work roll rotation angular rates disregistry full elimination. Then we perform piercing of the tubular billet, we perform the rolls rotation angular rates reference recording the under process duty and the further wall thickness test of the tubes after tubular billet piercing on the cross-roll piercer No1. If necessary, in a similar way we perform both drive stroke more subtle adjustment and the one of the cross-roll piercer work rolls.

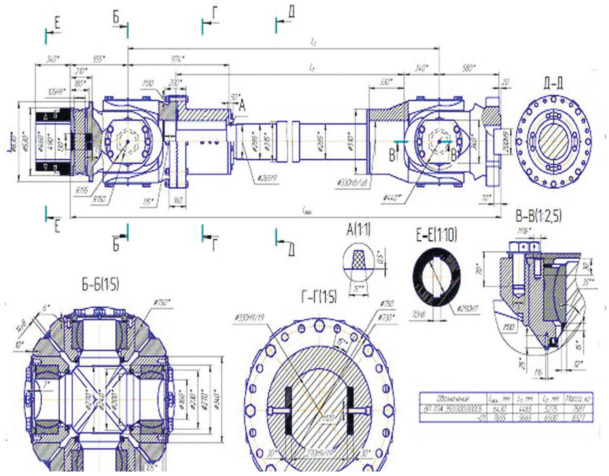


Fig. 9. Upgraded tubular mill 350 cross-roll piercer No1 multifaceted shafts with opportunity to control the stroke non-uniformity.

CONCLUSIONS

1. We made the differential equations of the tubular mill cross-roll piercer driveline elements movement, considering the changes in time of the driveline gimbal gear spatial arrangement and the work rolls cross-angle value. We provided numerical solution of the tubular mill cross-roll piercer driveline movement differential equations system.

2. We researched the tubular mill cross-roll piercer No1 work rolls drive line transient model based on the software product Solid Works IT Simulation X "Drive shaft". At the same time the tubular mill cross-roll piercer No1 main drive transient model with multifaceted shafts is represented in form of three masses J_1, J_c and J_2 linked between each other by the elastic linkages c_{12} and k_{23} with the damping elements b_1 and b_2. By simulating the dynamic processes, we determined the areas of mechanical system functioning withstandability depending on the mill operation regime, the tubular billet cross-angle value into the work rolls and the cross-roll piercer shaft unit elements spatial arrangement.

3. It was shown that mechanical system main drive elements parametric angular oscillations are the main reason why the results of cross-roll piercers experimental and theoretical studies do not match. We found the conditions of both the work rolls stroke non-uniformities and induced rolled tubes wall variation generation mechanism to occur.

4. We determined the tubular mill cross-roll piercer work rolls drive line self-standing (efficient) functioning areas by researching different transient models of the mechanical system. In order to monitor the work rolls stroke non-uniformities we offer the tubular mill cross-roll piercer main drive multifaceted shafts pin-and-eye connections upgrading plan.

5. The results of work can be used on similar screw rolling mill.

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