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Unsolved Problems of Modern Theory of Lengthwise Rolling

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Abstract
The conflicting arguments regarding interconnection between widening, forward creep and drawing under lengthwise rolling are specified. It is proved that under complete metal gathering the rolling process itself differs slightly from conventional rolling. The only distinguishing feature is change in the mechanisms of widening and forward creep. The abnormal growth of forward creep under increased reductions is observed. It is established that this abnormal growth cannot be explained from the point of view of modern theory of rolling.

Keywords: *lengthwise rolling, metal, working rolls, rolling theory*

Introduction

In recent years, analytical research methods with the application of computer engineering as well as computer simulation of metal forming are widely used. And today, thanks to these innovatons, we can not only carry out research more rapidly but also can analyze larger quantity of parameters and, as a result, get to the heart of the processes under investigation.

The results of new methods application in the computations of roll pass design for rolling of extra-complex sections are the most impressive from the point of view of their practical use.

Until recently, such roll pass designs were the subject of intuition and mastery of calibrator rather than engineering calculations. And today V.E. Grum-Gryzhymaylo's prediction has come into being and computation of roll pass design is really easy.

Statement of research problem and analysis of achieved level of developments

Unfortunately, any major innovation can cause negative consequences. And this particular case is not an exception. The experimental methods are sinking into oblivion, in some theoretical studies of rolling the physics of process is inadmissibly simplified, in others – the models that have nothing to do with the real rolling process and even sometimes the abstractions accepted are neither discussed nor stipulated. The only result of such research is information noise.

Moreover, the physics of rolling is not thoroughly studied. Some important statements are interpreted in different ways while some phenomena cannot even be explained from the point of view of modern theory of rolling.

Here are some examples.

1. It is known that the coefficients of forward and backward creep in the deformation zone are expressed in terms of elongation ratios in zones of forward and backward creep respectively. And the elongation ratio in one pass is simply the product of these ratios [1, 2].

Thanks to participation of forward creep in strip drawing, we start considering forward creep and drawing as a direct relation - the more drawing, the more forward creep. And vice-versa, I.M. Pavlov was the first who formulated this thought. [3]. To his mind, the larger drawing due to widening should enlarge forward creep as well. With widening, the strip drawing drops, and, as a result, the value of forward creep decreases. Consequently, widening initiates forward creep drop. Such arguments were expressed in a number of later studies.

From our point of view, these arguments are false. According to them, forward creep depends upon strip drawing. Meanwhile, as it was mentioned above, forward creep expresses only one part of drawing, namely drawing in the forward creep zone, where the conditions for lengthwise deformation are least favourable. And the drop of overall drawing should not be necessarily accompanied with the drop of its part, i.e. drawing in the forward creep zone.

To explain this phenomenon it is enough to mention the scheme of forces acting on metal in deformation zone. The horizontal projections of elementary friction forces and pressure are directed against each other in the backward creep zone. From one hand, the surface layers of metal pull in the specimen into the roll throat. From the other hand, deep layers of metal under effect of oppositely directed forces of pressure are squeezed from the deformation zone.

A. F. Golovin noticed this feature of roll force action on metal. He said that metal in the backward creep zone was not so much pushed rather than broached and drawn. Such a multidirection of forces that act on the strip in the backward creep zone promotes lengthwise drawing of metal and does not promote the development of crosswise deformation. Indeed, drawing in backward creep zone reaches 90 % and even more comparing to overall drawing, up to 100 %.

In a forward creep zone, the horizontal projections of specific forces of friction and pressure have the same direction which is opposite to rolling process. This fact creates the resistance to lengthwise movement of metal and promotes widening. Therefore, taking into account above considered arguments, increase of forward creep zone due to backward creep zone should promote further metal widening. And at the same time, the overall drawing should be less while a forward creep, vice versa, should be greater.

This is proved by well-known experimental dependences of widening and forward creep upon key parameters of rolling: roll diameter, reduction and friction coefficient, etc. Increase of one or some of these parameters is inevitably accompanied with the increase of both widening and forward strip. So, for example, increase of external friction coefficient (wear-out of roll surface) constantly promotes enlargement and widening of strip (overfill) and increase of forward creep, i. e. drawing in the forward creep zone while the overall drawing decreases.

Therefore, under otherwise equal conditions, formation of forward creep zone due to backward creep zone promotes increase in both forward creep and widening under reduction of overall strip drawing. As a result, we can draw the following conclusion: it is possible to increase the efficiency of rolling process due to increase of drawing ability of rolls and due to decrease of energy costs under operation with minimum possible forward creep.

2. The negative forward creep of metal is a subject of interest. To our mind, the classical definition of forward creep as the phenomenon of strip leaving the rolls at the rate that exceeds the velocity of roll periphery is out-of-date. According to this definition, it is impossible for forward creep to have a negative value. Meanwhile, the negative values of forward creep ("challenging cases of rolling" by A.P. Chekmaryov's and A.A. Nefedov's definition [6]) are observed in a wide range of cases [5] though individual but really existing processes such as periodic rolling, rolling in the rolls of unequal diameter or rotating with different frequency, rolling of high narrow strips, etc. So, for instance, there was a negative forward creep up to 12 % and more (without slips) [5] under periodic rolling of lead strip with dimensions 27x50x900 mm in rolls with variable radius and mean diameter 249 mm in the areas with variable reduction.

However, there are arguments that negative forward creep is not already a forward creep, it is a backward creep. It is really true by meaning. But both forward and backward creep have different values of strip and roll rate dismatch when metal is in and out of deformation zone respectively and, consequently, two values of forward creep.

Taking into account all above considered, it would be proper to define both backward and forward creep either as the phenomena of strip enter and exit from the rolls at the rate that differs from circumferential velocity of rolls with the further specification of these phenomena, or as mismatch of workpiece rate and circumferential velocity of rolls [2], but the latter is less desirable. In such a case, the expression "negative forward creep" would not cause any objections. But, the most important is to explain the nature of this phenomenon and to determine the conditions of its occurrence and limiting values of negative forward creep under which the rolling process is stable and has no slips.

By the way, in terms of widening we deal with the similar situation. For instance, the negative widening of metal can appear under high strips rolling, though by determination it cannot have negative value as well. This expression does not cause objections because it has a synonym – tightening and its nature is scientifically grounded [7].

3. One more contradiction is related to

phenomenon of the so-called *metal gathering* in deformation zone. Today, only a few scietitists will be ready to argue this phenomenon.

But, accepting the presence of partial or full metal gathering under definite conditions, many authors are mistaken about the aspects of development of widening, forward creep and drawing. So in one of the latest studies [9], we can find a statement that at complete metal gathering "…there is no drawing and the whole metal widens" (p.6). We also find the same in other references, for instance in the handbook [2]: "The widening coefficient is equal to reduction coefficient in gathering zone at the absence of metal particles sliding along the contact arc" (p. 163), i.e. the whole metal widens only. Naturally there should be nor forward creep neither drawing. But, since forward creep under rolling is undoubtedly established by most scientists, then there is metal sliding along the contact arc in the real rolling process and, in author's opinion [2], the complete gathering is absolutely impossible.

If we accept this point of view, it is reasonable to note that alongside with the absence of lengthwise sliding of metal particles along the contact arc, there will be the same situation (preferably) in crosswise direction also. Then it would be possible to state that in this case there is no widening and the whole metal elongates. But this does not occur.

The results of research

The failure of such arguments is that their authors use the main principles of fat cross-section hypothesis. During decades, this hypothesis was effectively applied to describe sheet rolling process, but it is completely unsuitable to describe high strips deformation process where the presence of complete gathering is more probable.

According to our research [1], there is a complete gathering during rolling of lead strips with ratio H/D = 0.5-1.0 in rolls with rolling-on in the contact surfaces. At the same time, the rolling process is stable while drawing, forward creep and widening continue developing but the mechanism of their formation differs. The measurement of unfinished sections with the coordinate grid that are stopped in the rolls proved that deep layers of metal are elongated along the whole area of deformation zone. Likewise conventional rolling with sliding, according to the law of least resistance, most metal reduced is shifted in opposite direction from rolling (backward creep zone), and the less part of metal - along the direction of rolling. But, this is not observed on the contact surface where velocity of metal particles coincides with velocity of metal perophery. The surface layers are elongated only in narrow areas near the planes of metal enter and exit from the rolls outside the geometrical deformation zone. This elongation of surface layers outside the roll center line is nothing else than the result of forward creep measured by method of core marks. But in the conventional process, elongation is formed due to metal particles sliding along the roll surface, and in this particular case - due to matching of metal particles outflow rates by workpiece height. This statement is in agreement with A.P. Chekmariov's conclusions concerning the nature of forward creep at complete gathering along the contact arc [7].

It is interesting to note that complete gathering of metal is observed also in crosswise direction but nevertheless widening in such a situation reaches the significant values. But, in this particular case, widening did not occur due to crosswise sliding of metal along the roll surfaces, but only due to metal transfer from side faces of strip upon contact surfaces. It can be well illustrated under hot rolling in vacuum. The initial main edges are easily seen on the surface of strip rolled, while on each side – the metal striae that have transferred from side edges on contact edges [10].

Figure 1 presents widening index as a function of reduction under rolling of samples made of 20 steel grade (C22E/ 1.1151) at 1200 ^{o}C in vacuum (a) and in the air (b).

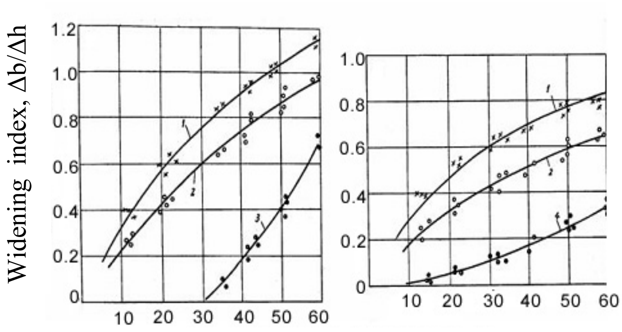

Figure 1. Widening index as a function of reduction of cross-sectional area under steel rolling in vacuum (a) and in the air (b): 1 – overall widening factor; 2 – reduced widening index; 3 – index of widening of contact surface due to metal transfer from side faces; 4 – the same, due to sliding.

It is clear from Figure 1 that complete widening formed by means of barrel distortion has a prevailing value. At reduction up to 30-40 % this element of widening is the only one. At reductions more than 30 % the widening appears as a result of metal transfer from side surfaces into contact surfaces. The further increase of reduction leads to sharp growth of this widening element.

Meanwhile, there is no widening progress as a result of metal sliding along the contact surface of roll, which proves the complete gathering of metal in the whole range of reductions.

When rolling in the air where the coefficient of contact friction is lower, the level of values of overall and reduced widening is also lower rather than in case of rolling in vacuum. However, widening which is a result of sliding along the contact surface of the rolls appears even under low reductions while widening due to metal transfer from side faces upon contact faces is almost absent.

Thus, the rolling process is stable under the presence of complete gathering along the contact arc both in lengthwise and crosswise directions. Like in conventional process, widening, forward creep and drawing are developing considerably. We should stress the following: under conventional process, the forward creep and widening are formed mainly due to metal sliding along the roll surface, while at complete gathering the forward creep (that is measured by method of core marks) is formed due to matching the rates of metal outflow outside geometrical zone of deformation and widening is formed due to metal transfer from side edges of unfinished sections upon contact surfaces.

4. One more contradiction. The numerous studies of metal forward creep demonstrated that within the increase of reduction, at first it increases, and then – having achieved a definite maximum value - decreases almost by symmetrical curve. The same conclusion results from the analysis of interrelation between angles of nip α, neutral cross-section γ and friction β suggested by I.M. Pavlov.

The different interrelation was found out under high reductions (40 % and higher). So, when rolling lead stripes with thickness of 12.5 mm in the rolls with 125 mm in diameter with roughed-rolled surface under small and large reductions, forward creep starts increasing in accordance with the principle described (Figure 2).

But, having achieved its maximum, forward creep slightly drops and then, at further increase in function reduction, rises drastically. The forward

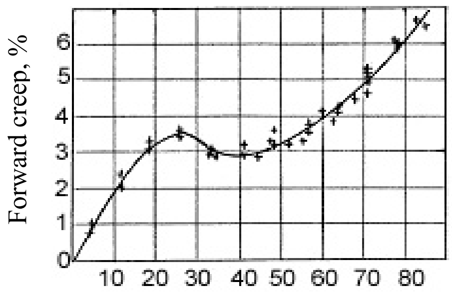

Figure 2. Forward creep as a function of reduction of cross-sectional area

creep reaches 6.8 % at reduction in 85 %. The function which is the same by quality is observed under hot rolling in smooth grinding rolls in vacuum[10].

Such an abnormal growth of forward creep under increased reductions cannot be explained from the point of view of modern theory of rolling. Meanwhile, explanation of such a phenomenon can considerably enrich our knowledge about kinematics and dynamics of lengthwise rolling process.

Conclusions

Despite the numerous research into theory of lengthwise rolling, there are contradictions related to interconnection between the key parameters of the process.

1. It is demonstrated that forward creep as a part of drawing promotes growth of crosswise deformation due to drawing.

2. The rolling process under complete gathering of metal differs slightly from the conventional rolling: there are changes only in the mechanisms of forward creep and widening formation respectively due to matching the rates of metal particles outflow along the workpiece height outside geometrical zone of deformation and metal transfer from side edges on contact edges.

3. The abnormal growth of forward creep under increased reductions that cannot be explained from the point of view of modern theory of rolling is specified.

4. The conditions of negative forward creep occurrence and its limit values, at which the rolling process is stable and has no slips, have not been established until now.

References

1. F.E. Dolzhenkov Operezhenie pri prokatke tolctykh polos (*Forward Creep under Plate Rolling*) // Proceedings of Ukrainian Scientific & Research Institute of Metals. – 1958. - Issue. 4. - P. 189-202.
2. D.I. Starchenko Kinematika prodolnoy prokatki (*Kinematics of Lengthwise Rolling*). – K.: UMK VO 1992, 275 p.
3. I.M. Pavlov, Ya.S. Gallay Operezhenie pri prokatke (*Forward Creep under Rolling*). – M.: ONTN, 1935.
4. A.F. Golovin Prokatka (*Rolling*). – Sverdlovsk-M.-L.: Metallurgizdat, 1933. - Part. I, 135 p.
5. P.A. Alexandrov, I.N. Filippov Operezhenie i ushyrenie pri pereodicheskoy prokatke. Tekhnologia proizvodstva i svoystva chernykh metallov (*Forward Creep and Widening under Periodic Rolling. Production Technology and Properties of Ferrous Metals*) - M.: Metallurgizdat, 1956. - Issue. 2, 185 p.
6. A.P.Chekmarev, A.A. Nefedov Operezhenie pri prokatke na valkakh raznogo diametra (*Forward Creep at Rolling in Rolls of Different Diameter*) Works by Iron and Steel Institute. Prokatnoe proizvodstvo. Issue 2. - K.: Publishing House. AA USSR 1957, P. 105-107.
7. A.P. Chekmarev et al. Teoriya prokatki krupnykh slitkov (*Theory of Large Ingots Rolling*). - M.: Metallurgia, 1968, 252 p.
8. A.P. Chekmarev O nekotorykh voprosakh teorii prokatki. Teoria prokatki. Materialovedcheskaya konferentsyya po teoreticheskim voprosam prokatki (*Theory of Rolling. Proceedings of Conference upon Theoretical Aspects of Rolling*). - M.: Metallurgizdat, 1962. - P. 31-56.
9. M.L. Zaroschinskiy K voprosu o pemeschenii metalla v ochage deformatsyy pri prokatke (*Metal Transfer in Deformation Zone under Rolling*) // Collection of articles “Obrabotka metallov davleniem” (Metal forming). - M.: Metallurizdat, 1958.
10. F.E. Dolzhenkov et al. Prokatka metallov v vakuume i inertnoy srede (*Rolling of Metals in Vacuum and Inert Atmosphere*) – K.: Tekhnika, 1964, 67 p.

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Нерешенные вопросы современной теории продольной прокатки

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Отмечены противоречивые суждения о взаимосвязи уширения, опережения, вытяжки при продольной прокатке. Доказывается, что и при полном прилипании металла к валкам процесс прокатки мало отличается от обычного, изменяется лишь механизм уширения и опережения. Отмечен аномальный рост опережения при повышенных обжатиях, который не может быть объяснен с позиций современной теории прокатки.