UDC 621.771

The Force Pattern in the Deformation Zone at Steady Rolling Process

Oginskyy Y.K.

National Metallurgical Academy of Ukraine
4 Gagarin Ave., Dnipropetrovsk, 49600, Ukraine

The analysis of the force pattern at steady-rolling process in the form in which it is applied in the modern theory of rolling is carried out. Inaccuracies in the existing approaches to estimation of the nature of influence, purpose and origin of forces are revealed. It is shown that existing assumptions about the force pattern in the rolling and, in particular, the scheme of forces have to be refined. The force pattern in the applicable form is a statically indeterminate problem and its solution requires additional initial conditions. Development and creation of methods based on volumetric flow of metal, in particular, on the basis of offset volume is considered promising.

Keywords: ROLLING, FORCE, EQUILIBRIUM CONDITION, FRICTION, WORK, MOMENT

Introduction

The force pattern at rolling was always the object of numerous investigations. This issue was rather actual during active development of rolling theory [1, 2]. The condition of longitudinal force equilibrium is emended [3], but as a whole the force pattern covers static condition. Recently the new technological regimes, in particular high-speed (rolling rate reaches 150 km/s), require more specific approach to definition of power parameters. It is determined in [4] that at high speeds (over 120 km/s) the dynamic component is in the force pattern which is capable to increase rolling force by 40 and more percents. Interest to rolling process dynamics is revealed at the rates which are rather small, but authors make an attempt to solve a problem in general and by that to get deeper insight into the force pattern [5]. The force pattern has also some inaccuracies which become obvious when estimating the force pattern in view of theoretical mechanics.

The task of present research is analysis and specification of approaches to determination of parameters of force interaction between metal and roll, clarification of force nature at rolling. Suggested approaches are based on regulations of mechanics. It is possible to specify the concepts about physical sense of forces and their pattern, methods of power parameters definition and other rolling theory issues researched not enough, in particular, kinematics.

Results and Discussion

From earlier works it is necessary to mention the force pattern (force scheme and explanations) showed in [6]. Unfortunately, some important rules of this work had no development. We note some of them (**Figure 1)**. Authors explaining the nature of force action write the following: "…there will be normal force N in any point S of roll surface at rolling. In this point force N will cause frictional force f·N tangent to roll surface due to displacement of roll surface". Special attention is paid to the following statement: "Rolling process can be carried out only if peripheral force of roll rotational moment will overcome this friction force… Force W acting from the roll on metal is equal to force T, i.e. W = f N". Here W - force of rolling torque or as authors call it [6] "peripheral force of roll torque".

As a whole, the sequence of forces and their application are covered physically rather correctly. In [1] A. A. Vinogradov analyzing the methods of power parameters determination shows the force patterns by other authors (Fink, Herman, Vereschagin), where the force applied from the rolls is also primary. Vereschagin calls this force "roll moving force". Its interconnection with other forces is characterized as follows [1]: "Force Po induces frictional force f·Po directed opposite to force Xo and equal to the last one". It is mentioned in [1]: Po - normal force, Xo - roll moving force. Despite the sufficient physical correctness of existing approaches [1, 6, etc.], a little different issues of force pattern appeared in rolling theory. In the current rolling theory the basis is a force pattern illustrated in **Figure 2**.

As for physical part of the force pattern of rolling process, it is possible to mention the issues that need to be specified. For this purpose we consider the basic mechanics of solid friction [7-9]. The force pattern at steady rolling process is accepted based on mechanics of solid friction in the technical literature. The scheme is shown in **Figure 3** [7]. We assume that there is no zone of slippage on the delivery side (forward flow is zero), then the pattern in **Figure 2** is changed as shown in **Figure 4**.

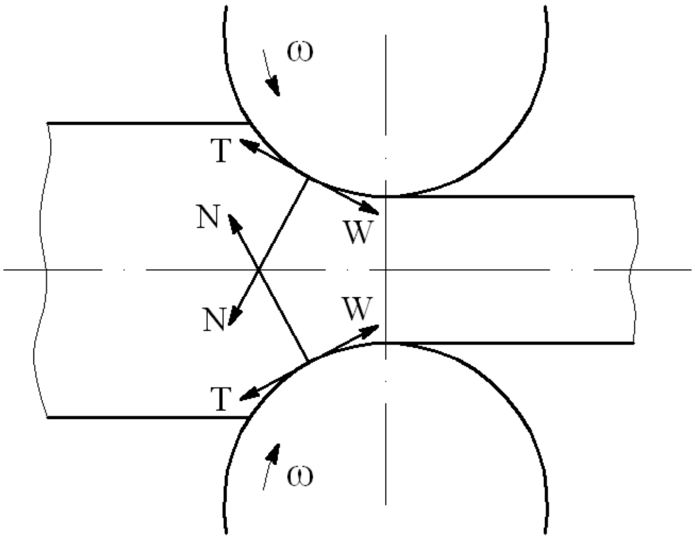

Figure 1. Force pattern at steady rolling process [6]

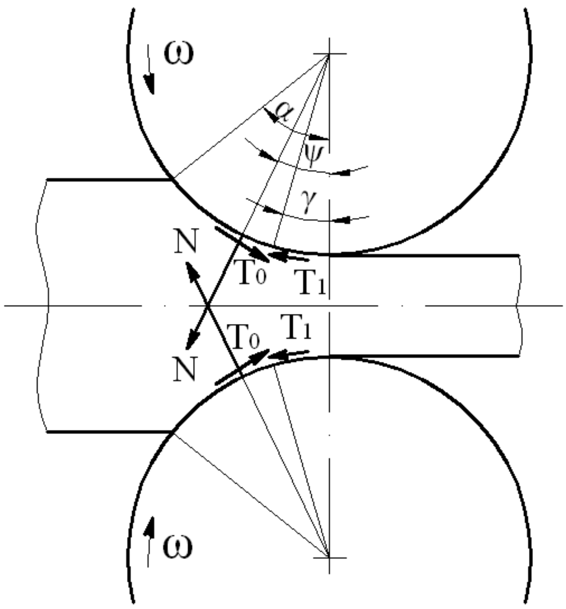

Figure 2. Force pattern at steady rolling process accepted in rolling theory

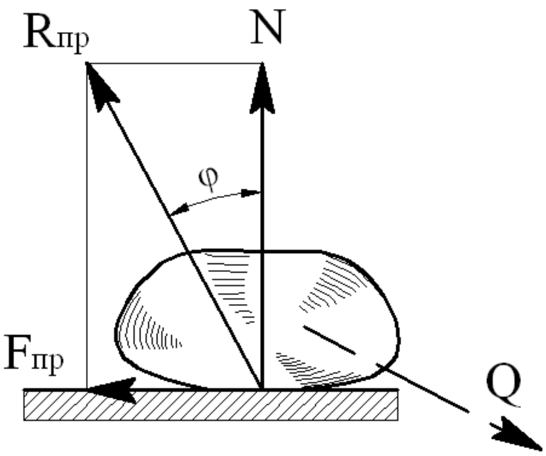

Figure 3. Force pattern at solid friction [7]

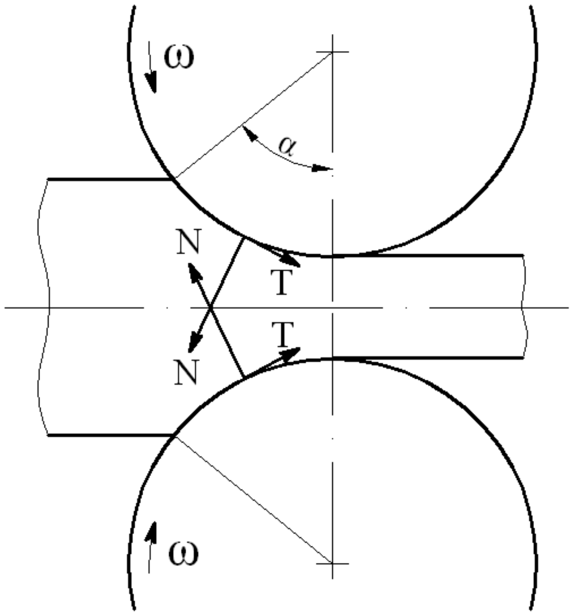

Figure 4. Force pattern at steady rolling process accepted in rolling theory, at S = 0

Comparison of force patterns in **Figures 3, 4** shows that they differ by cause-effect relationship of frictional force origination. According to mechanics principles [7-9] the external (shearing) force is a reason of frictional force formation. There is no external force in **Figures 4** (and, respectively, on **Figures 4**). It is written about the role of external force in standard [9]: “Frictional force”- resistance force at relative displacement of one body on the surface of another body under the action of external force, tangentially directed to common boundary between these two bodies”. There is an opinion in scientific and technical literature that functions of shearing force belong to frictional forces in the backward slip zone. This opinion contradicts the above-stated rules of mechanics.

The frictional force is reacting by definition and is one of the components of reaction occurring at solid interaction under conditions of external friction. This reaction has a special place. The force pattern is shown in **Figure 4.** In [7]: “Reaction of real (rough) bond is composed of two components: normal reaction N and perpendicular frictional force F. Hence, the complete reaction R will be inclined from a normal to surface on some angle”.

The equilibrium equation cited in rolling theory literature and used for solution of power and kinematic problems is a statically indefinable system. Various assumptions are used for its solution: one or another law of pressure distribution along the contact arch (linear, trapeziform, parabolic or others), laws by Amonton and Zibel are used for determination of force pattern of friction, or empirical dependences. The equilibrium equation does not cover the dynamic processes that take place in the deformation zone, in particular those considered in [5]. All shown patterns cover statically indefinable problem. The reaction of rough bond makes this problem indefinable, as this reaction is not defined by direct methods, for example, in [8]: “Reaction of rough bond is unknown by direction in advance. Therefore it is divided in two components: normal and tangential (frictional force). Modules of components are defined from corresponding conditions of solid G equilibrium” (solid G is movable).

Indeterminateness of force problem at rolling presented in static form is worsen by the fact that rolling process occurs under conditions of plastic friction which assumes physically other contact different from that takes place in mechanics where interaction of absolutely solids is observed. Body solidification principle is used in mechanics for deformable body (balance of changed (deformable) body under the action of given force system will not be broken if body is considered solidified), but it is applied at small deformations, mainly elastic. Kinematics of metal flow in the deformation zone also makes this problem indefinable. The presence of slip and sticking zones and, respectively, sliding friction and static friction within one surface of the contact does not allow using the uniform law (condition) of friction.

Following the rules of mechanics in works [7-9], it is possible to transform the pattern in **Figure 1.** The final pattern is illustrated in **Figure 5**. Approach based on equality of external and internal forces is more convenient for solution of applied problems. The features of external and internal forces can be expressed in terms of moment and energy of deformation respectively. The method of definition of energy of deformation and rolling torque on the basis of displaced volume is perspective [10]. The equality principle assumes a condition of force balance in the deformation zone as $\Sigma M = 0$. The force pattern shown in **Figure 5** corresponds to this condition.

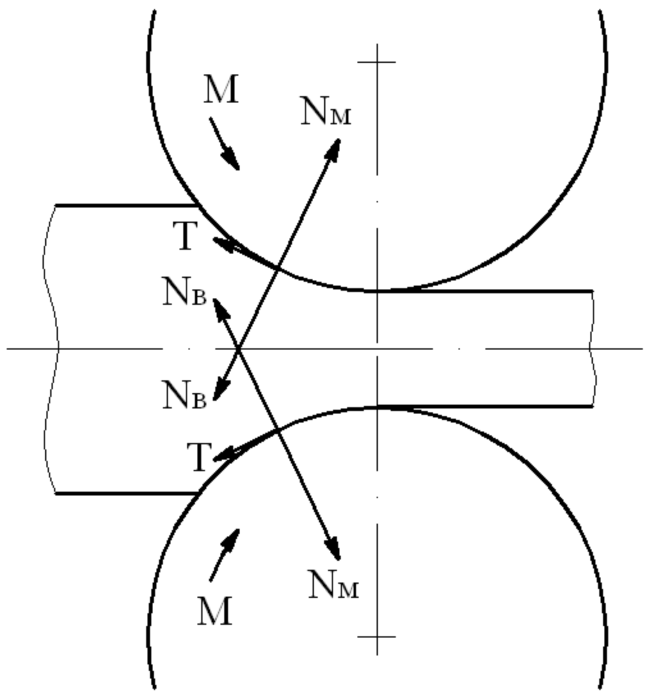

Figure 5. Force pattern at steady rolling process on the basis of [6], in which rolling torque M includes force W

Conclusions

The force pattern at steady rolling process is analyzed on the basis of mechanics rules in the form in which it is applied in the current rolling theory. Inaccuracies in existing approaches to estimation of nature, application and origin of forces are revealed. It is shown that current concepts about force pattern at rolling and, in particular the force pattern, need to be clarified. The force pattern is statically indefinable problem, and additional entry conditions are necessary for its solution. Development and creation of methods based on volume metal flow, in particular, on the basis of displaced volume, are perspective.

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* Published in Russian

Received October 05, 2010

Силовая картина в очаге деформации при установившемся процессе прокатки

Огинский И.К.

Выполнен анализ силовой картины при установившемся процессе прокатки в виде, в котором она применяется в современной теории прокатки. Выявлены неточности в существующих подходах к оценке характера действия, назначения и происхождения сил. Показано, что существующие представления о силовой картине при прокатке и, в частности, схема сил нуждаются в уточнениях. Силовая картина в применяющемся виде представляет собой статически неопределимую задачу и для ее решения необходимы дополнительные начальные условия. Перспективным является развитие и создание методов на основе объемного течения металла, в частности, на основе смещенного объема.