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Short report
Краткое сообщение

Reserves for reducing energy consumption when rolling section bars on modern rolling mills

A. R. Fastykovskii, **M. I. Glukhov, V. A. Vakhrolomeev**

Siberian State Industrial University (42 Kirova Str., Novokuznetsk, Kemerovo Region – Kuzbass 654007, Russian Federation)

fastikovsky@mail.ru

Abstract. Metallurgical production is a highly energy-intensive process, and the search for solutions to reduce energy costs remains an urgent task for all stages. In this regard, the production of finished rolled products is considered as the most promising direction for the implementation of energy-saving technologies. There are two ways to reduce energy costs in hot rolling of section bars: saving energy for heating and improving the use of the main equipment to reduce intermediate energy costs. Due to the difference in silt conditions at the moment of capture and at the steady stage of the rolling process, a reserve of retracting friction forces arises, which can be used for additional shaping in non-drive devices and thereby increase the efficiency of the main equipment and reduce overall energy costs. For the practical implementation of the proposed concept, dependence was obtained that makes it possible to estimate the power potential that is not used at the steady stage of the rolling process. Using the obtained dependence, it was found that when rolling in smooth rolls, the potential of friction forces is used only by 50 – 60 %, and when rolling in calibers, by 35 – 40 %. It was experimentally established that during the rolling of shaped sections in passes with an elongation ratio of less than 1.10 – 1.15, more than 50 % of the energy is spent on idling. However, by replacing drive stands in these passes with non-drive cassettes (in continuous groups), it is possible to increase the efficiency of adjacent stands by 4 – 5 % and reduce energy costs.

Keywords: energy consumption, section bar, non–drive stand, idling, efficiency

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Резервы снижения энергопотребления при прокатке сортовых профилей на современных прокатных станах

А. Р. Фастыковский, **М. И. Глухов, В. А. Вахроломеев**

Сибирский государственный индустриальный университет (Россия, 654007, Кемеровская область – Кузбасс, Новокузнецк, ул. Кирова, 42)

fastikovsky@mail.ru

Аннотация. Металлургическое производство является высокоэнергоемким процессом, поэтому поиск решений по снижению энергозатрат остается актуальной задачей для всех переделов. В этом плане производство готовой прокатной продукции рассматривается как наиболее перспективное направление для реализации энергосберегающих технологий. Возможны два пути снижения энергозатрат при горячей прокатке сортовых профилей: экономия энергии на нагрев и улучшение использования основного оборудования для снижения промежуточных затрат энергии. Ввиду разности силовых условий в момент захвата и на установившейся стадии процесса прокатки возникает резерв втягивающих сил трения, который можно использовать для дополнительного формоизменения в неприводных устройствах и тем самым повысить эффективность основного оборудования и снизить общие энергозатраты. Для практической реализации предложенной концепции была получена зависимость, позволяющая оценить потенциал мощности, который не используется на установившейся стадии процесса прокатки. С применением полученной зависимости было установлено, что при прокатке в гладких валках потенциал сил трения используется только на 50 – 60 %, а при прокатке в калибрах – на 35 – 40 %. Экспериментально установлено, что при прокатке фасонных профилей в пропусках с коэффициентом вытяжки менее 1,10 – 1,15 более 50 % энергии затрачивается на холостой ход. Однако заменив в этих пропусках приводные клети на неприводные кассеты (в непрерывных группах), можно повысить коэффициент полезного действия рядом стоящих клетей на 4 – 5 % и снизить энергозатраты.

Ключевые слова: энергопотребление, сортовые профили, неприводная клеть, холостой ход, коэффициент полезного действия

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Metallurgical production is considered one of the most energy-intensive industries, consuming up to 90 % of coking coal, 50 % of generated electricity, and 25 % of natural gas [1]. The final stage of metallurgical processing, known as rolling production, requires a significant amount of fuel for both heating the billet before rolling (1.30–1.65 GJ/t) and during the rolling process itself (0.45–1.20 GJ/t) [2]. These figures convincingly highlight the importance of efforts to reduce energy costs in rolled product manufacturing.

Enhancing the utilization of friction forces within the deformation zone of a rolling stand represents a key opportunity for reducing energy consumption in the production of section bars on modern continuous rolling mills [3 – 5]. By doing so, the overall efficiency of the primary rolling equipment can be increased. To implement this approach, additional non-driven devices, located in close proximity to the drive stands, can be employed for the deformation or longitudinal separation of the strip [6 – 9].

It is widely recognized that the rolling process relies on friction forces between the metal and the rolls. The more effectively these friction forces are harnessed during the forming process, the higher the process efficiency and the more efficiently energy is utilized. However, the varying force conditions during the initial gripping of the metal by the rolls and during the steady stage of the rolling process create circumstances where the potential of friction forces within the deformation zone is not fully realized. Addressing this issue necessitates the use of continuous devices, such as rolls and dividing devices, which facilitate additional work to be performed.

In order to quantify the untapped potential of friction forces during the steady stage of the rolling process, we can calculate the unused power (ΔN) by considering the disparity in friction coefficients between the gripping phase (μ_g) and the steady stage (μ_s) of hot rolling, where $\mu_g/\mu_s \approx 1.2 \div 1.4$ [10]. This can be determined using the equation:

$$\Delta N = N_s - N_d,$$

where N_s represents the power that can be generated by friction forces during the steady stage of hot rolling; N_d is the power required for deformation in the driven stand.

The maximum power generated by friction forces during the steady stage of hot rolling (assuming a zero-length advance zone) can be calculated using the equation:

$$N_s = 2p_{avg}\mu_s b_{avg} l_d v,$$

where p_{avg} denotes the average normal pressure; b_{avg} represents the average strip width; l_d is the length of contact arc; v is the rolling speed.

To determine the power required during deformation, we utilize the well-known Fink equation [11], with the substitution:

$$\Delta h \approx h_{avg} \ln\left(\frac{h_0}{h_1}\right),$$

where Δh is the absolute reduction; h_{avg} is the average strip height; h_0 and h_1 refer to the strip height before and after rolling in the driven stand, respectively.

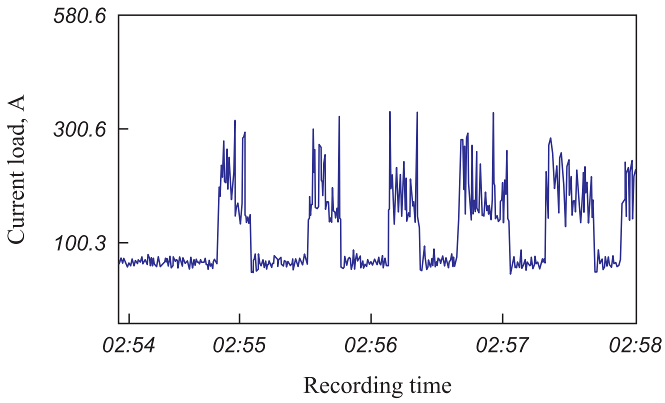
It should be noted that this assumption introduces an error of 1 – 3 % for degrees of deformation up to 60 %. After appropriate transformations and incorporating the μ_g/μ_s ratio, we obtain:

$$\Delta N = p_{avg} b_{avg} v\,(1.54\mu_g l_d - \Delta h).$$

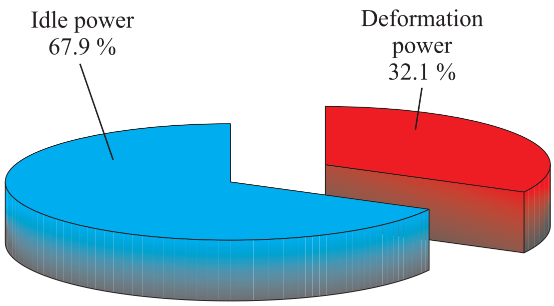
The obtained ΔN value makes it possible to estimate the unused potential of friction forces in the deformation zone during hot rolling. The calculations reveal that, when rolling a rectangular strip on smooth rolls, only 50 – 60 % of the maximum potential of friction forces is utilized under maximum reductions and 35 – 40 % in subsequent passes due to differences in force conditions between gripping and the steady stage of rolling. This inefficiency significantly impacts the rolling process, resulting in increased energy consumption. Therefore, the implementation of non-driven devices for deformation and longitudinal separation is recommended.

To enhance the efficiency of rolling bars, a more complete utilization of the potential of friction forces can be achieved by replacing driven stands with non-driven ones in sections where the elongation coefficient falls below 1.10 – 1.15. Fig. 1, *a* presents a diagram illustrating the recording of the current of the main engine in the second stand of a medium-section mill during the production of angle No. 9, with a drawing ratio of 1.03. Fig. 1, *b* depicts the power distribution for this case, with the majority of power being used for idling (67.9 %), while only a small fraction (32.1 %) is allocated to product formation. To address this issue, the implementation of a non-driven stand, specifically a cassette, in place of the drive stand for the given pass can be considered. This adjustment enables the redistribution of power for product deformation across adjacent stands from the same group without the need for stopping. Such an approach will lead to a reduction in energy costs by minimizing idle power consumption and an increase in the efficiency of adjacent stands (Fig. 2).

The medium-section mill being considered has an assortment comprising 83 % of shaped profiles, such as angles, beams, and channels. Within this assortment, there are sections with an elongation ratio of less than 1.10 – 1.15, indicating areas where improvement is needed. By incorporating non-driven stands



a



b

Fig. 1. Energy costs during rolling in the second stand of the middle-grade mill with drawing coefficient 1.03:
a – current diagram of the main motor;
b – energy balance in the considered stand

Рис. 1. Энергозатраты при прокатке во второй клети среднесортного стана с коэффициентом вытяжки 1,03:
a – токовая диаграмма главного двигателя;
b – энергетический баланс в рассматриваемой клети

in these passes, and with an annual production output of 1.4 million tons of finished products, energy savings of up to 0.75 kWh/t can be achieved. In monetary terms, this translates to an annual savings of 4.8 million rubles. Additionally, the use of non-driven stands in the form of cassettes results in reduced metal consumption, costs, depreciation deductions, and operating expenses compared to traditional rolling stands. This provides an additional benefit of 15 million rubles per year. Considering the costs associated with manufacturing the new equipment, the investment in non-driven stands is projected to have a payback period of 0.8 years.

Conclusions

During the steady state stage of hot rolling, there exists an untapped potential of frictional forces in the deformation zone due to the differing force conditions between gripping and the steady state stage of the process. This inefficient utilization of energy can result in suboptimal performance.

In order to enhance the efficient utilization of frictional forces in the deformation zone during the steady

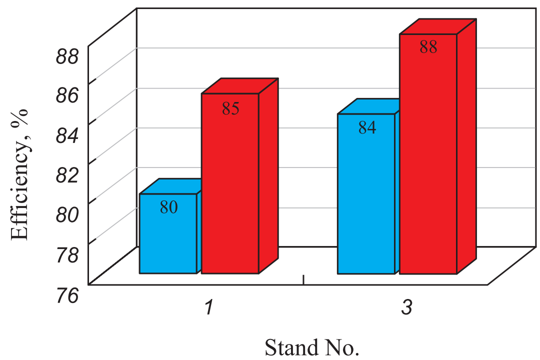


Fig. 2. Change in efficiency of *1* and *3* stands when replacing the second stand with a non-drive stand – cassette

Рис. 2. Изменение коэффициента полезного действия *1* и *3* клетей при замене второй клети неприводной клетью – кассетой

stage of the rolling process, it is proposed to incorporate non-driven devices in close proximity to the driving stands for additional deformation and longitudinal separation. Research indicates that when the drawing ratio falls below 1.10 – 1.15, it is advisable to replace the drive stands with non-drive stands. This approach not only reduces energy consumption and operating costs but also enhances the efficiency of the primary equipment.

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Information about the Authors

Andrei R. Fastykovskii*, Dr. Sci. (Eng.), Prof. of the Chair “Metal Forming and Metal Science. OJSC “EVRAZ ZSMK”*, Siberian State Industrial University
ORCID: 0000-0001-9259-9038
E-mail: fastikovsky@mail.ru

Maksim I. Glukhov*, Postgraduate of the Chair “Metal Forming and Metal Science. OJSC “EVRAZ ZSMK”*, Siberian State Industrial University
E-mail: Gluhovmx@yandex.ru

Vladimir A. Vakhrolomeev*, Postgraduate of the Chair “Metal Forming and Metal Science. OJSC “EVRAZ ZSMK”*, Siberian State Industrial University
E-mail: wladimir170581@mail.ru

Сведения об авторах

Андрей Ростиславович Фастыковский*, д.т.н., профессор кафедры «Обработка металлов давлением и металловедение. ЕВРАЗ ЗСМК»*, Сибирский государственный индустриальный университет
ORCID: 0000-0001-9259-9038
E-mail: fastikovsky@mail.ru

Максим Ильич Глухов*, аспирант кафедры «Обработка металлов давлением и металловедение. ЕВРАЗ ЗСМК»*, Сибирский государственный индустриальный университет
E-mail: Gluhovmx@yandex.ru

Владимир Анатольевич Вахроломеев*, аспирант кафедры «Обработка металлов давлением и металловедение. ЕВРАЗ ЗСМК»*, Сибирский государственный индустриальный университет
E-mail: wladimir170581@mail.ru

Contribution of the Authors

A. R. Fastykovskii – formulation and solution of the problem of determining the power reserve during rolling at a steady stage of the process, theoretical analysis of the prospects for using the reserve of friction forces during rolling, justification of the extraction coefficients at which it is advisable to replace the drive rolling stands with non–drive devices, formulation of conclusions based on the results of research.
M. I. Glukhov – obtaining and analyzing experimental results, evaluating the economic effect of using the reserve of friction forces on the operating mill.
V. A. Vakhrolomeev – analysis of literary data, design of the graphic part, evaluation of the possibility of increasing the efficiency when using the reserve of friction forces.

Вклад авторов

А. Р. Фастыковский – постановка и решение задачи по определению резерва мощности при прокатке на установившейся стадии процесса; теоретический анализ перспектив использования резерва сил трения при прокатке; обоснование коэффициентов вытяжки, при которых целесообразно приводные прокатные клети заменять неприводными устройствами; формулирование выводов по результатам исследований.
М. И. Глухов – получение и анализ экспериментальных результатов, оценка экономического эффекта от использования резерва сил трения на действующем стане.
В. А. Вахроломеев – анализ литературных данных, оформление графической части, оценка возможности увеличения коэффициента полезного действия при использовании резерва сил трения.

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