

Heavy Metal

Current views on the detailed design of heavily loaded components for rolling mills by Vladen Mazur, Viktor Artyukh, Gennady Artyukh and Maryna Takadzhi.

Ukraine is a developing European country and part of the CIS (Commonwealth of Independent States). Its iron and steel, and heavy engineering industries provide equipment and spare parts for steel working around the world. They are key industries for its domestic and external markets, producing finished products for export with a total value of about £9.1 billion, approximately 45.3% of total Ukrainian exports.

The most promising area for increasing the production of steel making equipment appears to be rolling mills. They carry heavy loading, which would have to be raised to improve productivity. It is important that parts are modified to avoid overloads, accidental breakdowns and downtime of expensive equipment.

In the design, modernisation and repair of different types of mechanical equipment, it is often wrongly stated that 'The larger the part is, the stronger it should be'. Using the results of theoretical and experimental research, stress analysis, technical and scientific developments of different pieces of metallurgical equipment, industrial commissioning and so on, we suggest using new approaches to better understand the relationships between strength, durability and the dimensions of such parts. Any heavy loaded machine, its assemblies and subassemblies must be considered as a whole set of elastic systems if there is to be no permanent deformation. These systems

interact with other systems generating new load patterns. New technical procedures are provided to take account of higher loads and forces where strength and stiffness of equipment are crucial.

These loads may be classified according to their function:

1. Necessary loadings arising from operations, eg material rolling (see figure 1), transport (see figure 3), and flattening rolled products. Engineers can calculate these loads using the well-known proven formulas.
2. Unnecessary additional loads arise where the equipment is not optimised for the loading. Such loads act in addition to the functional loads and their elimination would improve the efficiency of all types of equipment. Their accurate determination must be performed individually for every load case or by experimental testing. For example, the main types can be illustrated using the hot thick strip four high working stand shown in figure 1:
 - Additional impact loads (forces). Examples are direct blows of rolled metal 1 against rolling rolls (RR) 2 during metal biting, impacts of chocks 3 and 4 of RR 2 and backup rolls (BR) 5 against frames 6;
 - Additional loads from incorrect positioning of contact surfaces on rolling stand parts. The main reasons are: gaps, misalignments and poor

installation of the parts. In summary, it is the increase of horizontal forces F_{hor} due to impacts of chocks 3 of RR 2 and 4 of BR 5 against frames 6 during rolling because of growing gaps Δ_1, Δ_2 and Δ_3 between facing strips 7, 8 and lining straps 9, 10 and 11. Moreover, inside many modern rolling stands there are hydraulic cylinders (HC) 12 for pressing RR 2 to BR 5 in final design position as it is shown on figure 1 and figure 2. The contact surfaces on lining straps 9 and frames 6 are loaded by horizontal forces, which may deform them, adversely affecting their performance;

- Additional vibration loads. These appear in the main drives in the form of dynamic oscillations. They can arise from two main sources:
 - √ from differences between the design and actual erection positions.
 - √ from wear of main drive components, eg gaps Δ_4 and Δ_5 between contact surfaces of clutches 13 and spindles 14.

The purpose of this classification is to show that the key problems of increasing overall dimensions of elements are significant increases in loads leading to high wear, fatigue damage and accidental breakdowns. In practice, design engineers define the equipment in detail but cannot influence the accuracy of the assemblies and the wear of components, which frequently cause loads to increase. It is necessary to prevent these loads reaching dangerous levels by providing for shock absorbers to be installed from an early stage of the design. Several examples are given later.

Vibration absorption needs careful consideration. There is a need to understand them not as 'force and load' but as 'kinetic and potential energies'. During an impact the kinetic energy of moving parts converts into the potential energy of deformation. In order to reduce loads arising from this conversion we need a shock absorber between interacting pieces of equipment to absorb and disperse energy as heat.

The results of theoretical and experimental research show contact force values of opposing parts of metalworking equipment depend on the stiffness of contacting parts: the greater the stiffness, the higher the contact forces. That, in turn, defines the required strength of parts and assemblies. By reducing the stiffness of contact pairs it is

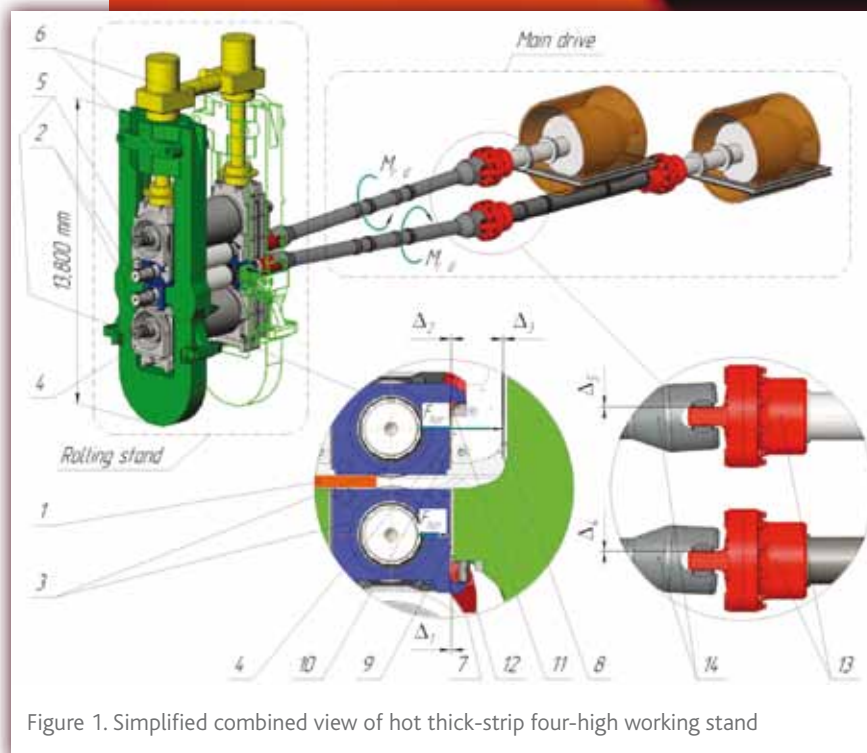


Figure 1. Simplified combined view of hot thick-strip four-high working stand

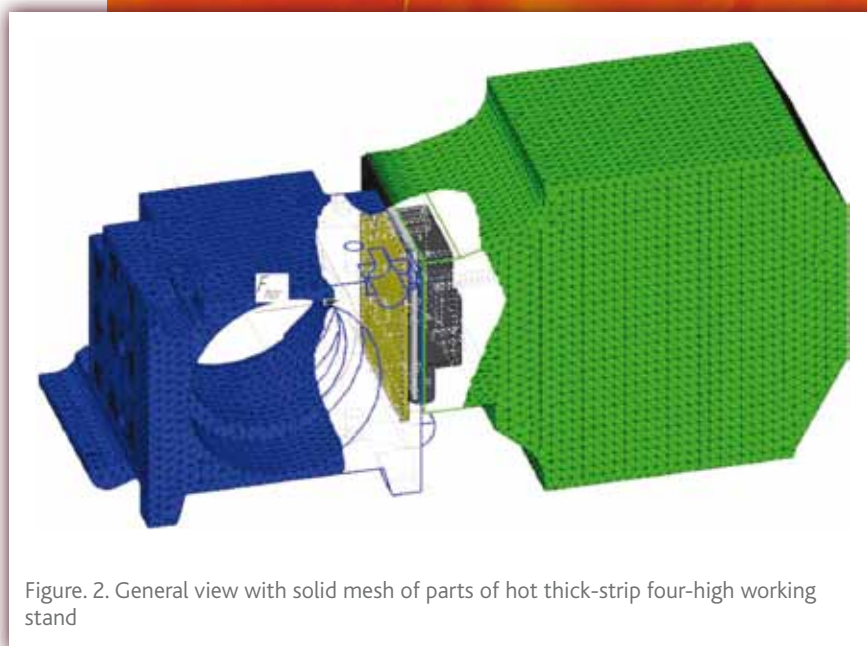


Figure 2. General view with solid mesh of parts of hot thick-strip four-high working stand

In the design, modernisation and repair of different types of mechanical equipment, it is often wrongly stated that 'The larger the part is, the stronger it should be'

possible to make contact forces smaller and to lessen consequent additional loads. Devices such as shock absorbers (with their variable stiffness using modern high energy capacity materials) are used in a lot of iron and steel works, and their use continues to grow.

Among the most successful and original design cases of commissioning and using shock absorbers inside the main rolling equipment, both technically and economically, are:

1) installation of polyurethane lining straps 9 and 10 instead of steel ones on chocks 3 of RR 2 (refer to figure 1) where the former have almost the same geometric design as the latter. During the design, the Finite Element Method (FEM) was used to carry out the stress analysis of the assembly of components 3, 9, 7, 12 and part of 6 (refer to figure 1). A horizontal force of 2 MN (450,000 lbf) was applied on the inner part of the rolling bearing of the chock 3 of lower RR 2. The interactions between contact surfaces, with different steel strength characteristics, of these parts with the same geometric design and measurements are as expected. Figure 2 shows the results of FEM stress analysis of the base assembly of components of the roughing hot thick-strip reversing four-high working stand of the Plate Mill Shop (PMS) 3000 of Pjsc 'Ilyich Iron And Steel Works of Mariupol' (hereinafter referred to as 'Ilyich Works'). Calculating the von Mises yield stress (please see table on right) and the compression stress allowed the selection of the most appropriate polyurethane grade for the lining straps with a sufficient safety factor for their industrial use. The maximum compression of approximately 0.18 mm of the polyurethane-lining strap in the direction of the horizontal force is acceptable.

The significant reduction of von Mises yield stresses in components of the working stand was achieved by the use of a high-energy-capacity polyurethane lining strap on the chock of RR. If the energy capacity of the working stand with all steel parts and polyurethane lining strap is compared to the conventional steel system, an

Material of lining strap	Detail			
	Chock of lower RR (Steel 30XГСФЛ. CIS State standard (SS) 977-75)	Facing strip (080 M 46. B.S. 970)	Body of HC for pressing lower RR (Steel 25X2M1Ф. CIS SS 20072-74)	Frame (Steel 161 grade 430. B.S. 1504 (76))
080 M 46. B.S. 970	59,465	121,983	64,427	49,952
Polyurethane 'Adipren' (CIS)	40,279	19,903	28,025	32,098

Table – Maximum calculated values of von Mises yield stresses (MPa) in components of the roughing four-high working stand



improvement by a factor of ten is observed. This matches the theoretical reduction of generated loads, n , as given by:

$$n = \sqrt{\frac{E_{st}}{E_{pol}}}$$

E_{st} is the Elastic Modulus of steel;
 E_{pol} is the Elastic Modulus of polyurethane.

A new set of polyurethane 'Adipren' grade

lining straps (eight items) was installed on RR chocks of the roughing four-high working stand of PMS 3000 and it has been in use for more than 21 months showing a significant economic benefit. A Ukraine patent, number 42803, protects this solution. Polyurethane lining straps on RR and BR chocks of the other four-high working stands are expected to be fitted later.

2) Installation of small shock absorbers on the base of the outer rings of rolling bearings. In general, rolling bearings assemblies are stiff

constructions, undergoing significant additional loading. According to the results of industrial usage of rolling bearings 1 (refer to figure 3) in heavily loaded rolling tables 2, (slabbings and thick strip rolling mills, outlet furnace rolling tables, etc) for transport of rolled metal 3, the service life is short, from six to twelve months, depending on their conditions of use.

To increase the durability of these rolling bearing assemblies, a small-sized shock absorber 4 was installed on the base of the outer ring of each rolling bearing 1. They were produced from polyurethane in a form of an undivided ring from 5 to 20 mm thick. The contact surface required quality depended on the total applied radial force (refer to figure 3).

The durability of rolling bearings with small-sized shock absorbers on them on the rolling tables of roughing stands group of PMS 1700 of PJSC 'ILYICH WORKS' has increased dramatically from six to twenty four months. Similar shock absorbers on the rolling bearings of conical rolling tables of PMS 3000 provided an increase in bearings durability from four to thirty months. This small change has produced a useful reduction of impact loads on rolling table rolls again showing a significant economic benefit.

In addition, the thickness and width of the polyurethane ring can be adjusted to reduce the radial force two or even three times through better distribution of the forces between steel and polyurethane contact surfaces. It allows the use of rolling bearings of smaller diameter.

3) Installation of a shaft-energy accumulator (refer to figure 4) in the main drive of the rolling stand. This allows the time of metal biting during rolling to be increased two to three times. Its damping coefficient (equal to about 0.3) was established experimentally. Moreover, damping can be significantly increased by the usage of additional friction between polyurethane elastic shaft 2 and cylindrical tube 3 (refer to figure 4, where 1 – half-clutch; 2 – polyurethane elastic shaft; 3 – cylindrical tube; 4 – pin). An experimental shaft, which can provide dynamic rolling torque up to 250 kNm

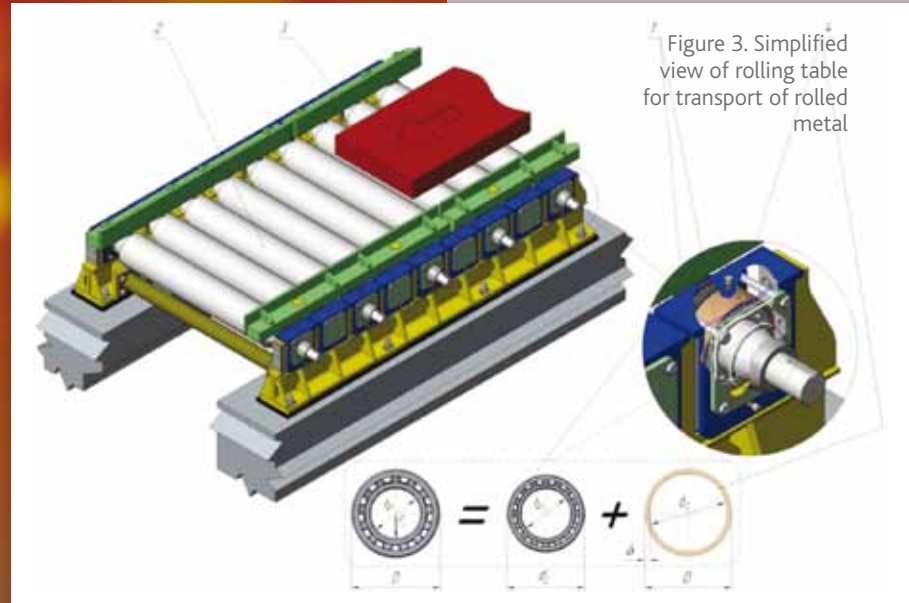


Figure 3. Simplified view of rolling table for transport of rolled metal

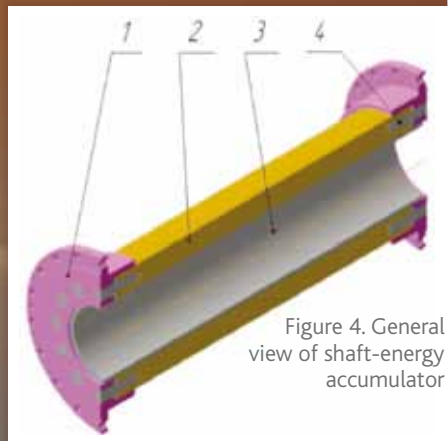


Figure 4. General view of shaft-energy accumulator

parameters such as stiffness and energy capacity. This means there is a need to absorb additional loads and forces, to reduce their values to safe levels, during operations. The strengths of elastic systems, where additional loads act, depend on stiffness and energy capacity. There are now real industrial examples of commissioning and use of some types of polyurethane shock absorbers. They prove in practice that in many cases it is possible to improve their durability yet avoid increasing the size of parts, using stronger steel grades and more expensive thermal treatments during their production. There is technical evidence here of a new approach where it is clear that components with shock absorbers have better durability than larger components of similar design.

(184,000 lbfft) and an angle of twist of about 180 degrees, will be installed soon in the main drive of rolling stand number 4A of PMS 1700 of PJSC 'ILYICH WORKS'.

Conclusion

Design engineers of steel processing equipment, and staff responsible for its supervision and repair should recognise that the initial load settings on equipment are often incorrect. Additional dynamic loads usually arise in systems that depend on

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