PQF/MPM — peculiarities of design of the continuous mandrel mill

Y. L. Ershov, B. I. Tartakovsky
Elektrostal Heavy Engineering Works (EZTM)

Introduction

JSC "Elektrostal heavy engineering works" (Russia, Elektrostal) is one of the largest Russian heavy industry enterprises. The company was established in 1942. For its long 67 years existence the enterprise manufactured and supplied equipment for more than 40 countries Worldwide.

Nowadays JSC "EZTM" is a state-of-the-art company, independently providing design, manufacture and supply of complex equipment for tube rolling, tube welding, finishing and coating equipment as well as cold rolling tube mills, medium section and small section mills, wiring mills, component rolling mills, ball rolling mills & other special purpose mills, oil film bearings, steel rolls for cold and hot rolling mills, and spare parts for manufactured equipment.

JSC "EZTM" produces unique equipment. Nearly each machine, mill or rolling complex is created (designed and manufactured) according to customers individual orders and drawings, and meet all specific requirements of the user. Thanks to long-term work in this direction our enterprise obtained significant experience and has its own school of tube rolling equipment manufacture.

JSC "EZTM" has wide continuous tube rolling mills design and start-up experience. JSC "EZTM" is the only manufacturer In the World who managed to produce floating plug continuous mill plants having annual capacity of 700000 tones of tubes within diameter range 30–102 mm (TPA 30-102 Russia, Pervouralsk and TPA 30-102 Ukraine, Nicopol).

JSC "EZTM" steadily participates in international tenders for similar projects, as an enterprise experienced enough in this field. Presently the vast majority of the customers stipulate PQF plants (multi-stand three-high continuous mill) in their inquires more than often. The main reason is a huge advertising campaign arranged by the company SMS Meer (Germany), which is an originator and foremost the first supplier of three-high rolling technology for continuous mills, on a wide industrial scale.

The main advantages of the three-high scheme are: minimum difference of circumferential speeds of the roll on the surface of the area of its contact with the metal during the deformation and less quantity of mandrel standard sizes due to the greater value of the roll radial adjustment towards the mandrel. Minimum difference of circumferential speeds should give an effect in part of roll wearing decrease and tube surface quality improvement. Minimum quantity of mandrel standard sizes means a decrease of tool maintaining costs. These are two announced features that gave an impulse to PQF method wide advertising campaign.

The said technology careful analysis performed by JSC "EZTM" technical specialists on the basis of available information made them come to evident conclusions. As a rule holding negotiations with customers JSC "EZTM" shows restrained optimism with regard to three-high continuous rolling technology advantages in comparison with conventional two-high, announced by SMS. Russian specialists informed their German colleagues about the troubles which will be met by PQF mill customer, more than once. In the meantime, information recently coming from enterprises exploiting the above mills essentially confirms anxiety declared earlier. However, (and this as good work done by SMS Meer marketing department) the number of inquires for three-high continuous mills increases day by day. We believe it is a high time to explain design and technological features of both technology schemes now.

First of all this article purposed for provision of eventual buyers with wider information required for choice making with respect to the most efficient for own hot rolled tubes manufacture technological chain.

Prior to description it should be noted that to enable the high readership to understand the below information clearer, there are some simplifications which will be easily recognized by experienced millmen. In addition to this, in spite of modern computer technologies achievements (finite elements stress method), we will recollect conventional methods for technological parameters analysis, to disclose the method of results obtaining more understandable.

It should be mentioned that the calculations given below were done just to compare both rolling schemes and can not be accepted for operation, as they do not consider a number of facts (e. g. influence of neighboring mill stands on each other, metal tension between stands and others).

Actually it is not possible to compare the plants with MPM and PQF reeling mills in real life. The difference of reductions distribution between the piercing and reeling mill in these two plants is too high. The above mentioned plants have different technical and technological limitations (this will be explained later on). That is why the below given data should not be compared with real schemes of rolling at existing mills. We chose the virtual scheme of roll borings for both schemes upon the condition of the same deformation parameters to carry out the comparative analysis.

Comparative analysis of two technological rolling schemes in the continuous mill with retained mandrel is made on the basis of technical characteristics given in the inquiry received from one of the eventual customers. According to the assignment, it is required to design tube rolling plant with continuous reeler on retained mandrel.

The product mix is hot rolled tubes having diameter ∅120...426 mm with wall thickness 6...40 mm.

Technological process

The product mix mentioned above, is divided on several ranges, each several is rolled from own billet. Enlarged technological process of tube manufacture on plant with continuous mill with technological parameters for the maximum tube size range, is given below.

Billet heating:	
Billet diameter, mm	440
Billet length, m	2...4
• **Billet piercing at two-high screw rolling piercer:**	
Shell diameter, mm	502
Wall thickness, mm	27...58,2
Shell length, m	6...11
• **Rough tube rolling in continuous mill MPM/PQF:**	
Tube diameter, mm	456
Wall thickness, mm	9,4...39,2
Tube length, m	28
• **Tube extracting form the mandrel on tube extractor:**	
Tube diameter, mm	438
Wall thickness, mm	9,5...39,8
Tube length, m	28,4
• **Tube sizing at sizer:**	
Tube diameter, mm	359,6...430
Wall thickness, mm	10,1...40,4
Tube length, m	36
• **Cooling at cooling bed:**	
Tube diameter, mm	356...426
Wall thickness, mm	10...40
Tube length, m	6...14,6

Deformation parameters geometrical peculiarities

There are three main deformation zones during the shell rolling on mandrel both in two-high and in three-high stand:

— Intense wall reduction zone on mandrel (marked in dark grey on Fig. 1, 2);

— Transition zone, where the stepwise decrease of wall reduction intensity on mandrel as carried out (marked in light grey on Fig. 1, 2);

Metal free spreading zone (“outlets” or “flange” zone), where the metal does not touch the mandrel and has a possibility to spread comparatively freely within the limits of, bounded by roll groove lateral surfaces, and extended thanks to the friction on the same lateral surfaces and at the expense of heated metal media uniformity (marked in black on Fig. 1, 2);

Thus the dimension of intense deformation zone is 90° in case of two-high option. This is exactly what is shown on Fig.1. Let’s denote this option as an “ideal”. In practice the wider angles (from 100° up to 120°) are used for this zone. This variant of boring we will study for the more precise visualization and comparison. Let’s accept the diameter of boring of the intense deformation zone as equal to 476 mm. Then we will build the “ideal” option of two-high scheme of rolling (ref. fig. 1). Maximum deformation of tube with respect to its diameter is defined not only by the angle of metal gripping by the rolls, but also by the possibility of shell entry into the interroll gap formed by the roll borings i. e. the width of the gap formed by the flange zones (or outlet zones) should be larger in comparison with shell diameter taking into account the metal widening within the process of rolling. After the calculations we defined that the max. diameter of the shell can be 570 mm. in our case (ref. fig. 1).

Now we can built the same “ideal” variant of roll borings for the three-high scheme (PQF mill). The dimension of wall intense deformation zone will be 60° (ref. fig. 2). Let’s accept the roll boring diameter as equal to 476 mm. as we did in case of two-high option (ref. fig. 2).

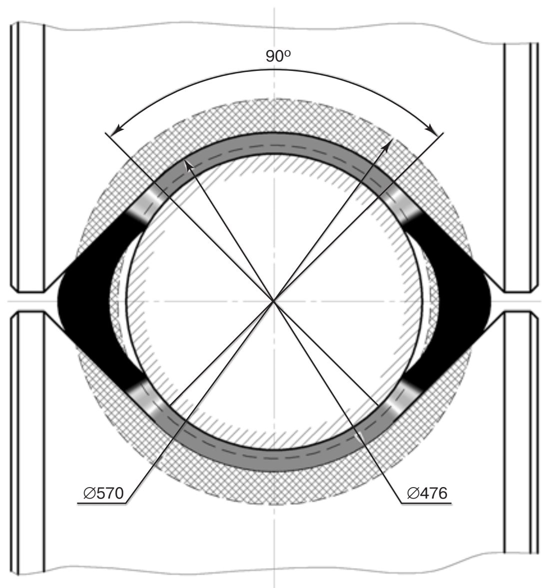

Fig. 1

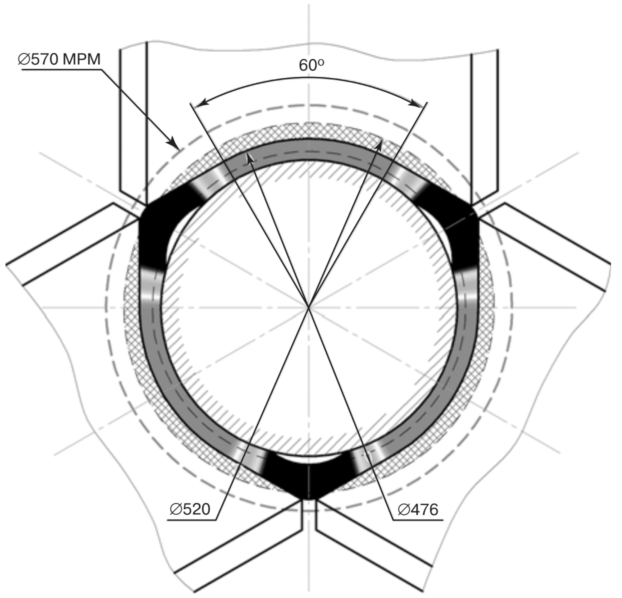

Fig. 2

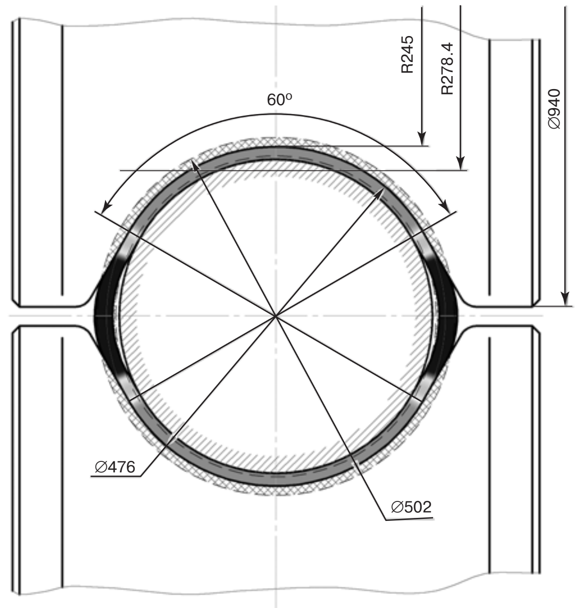

Fig. 3

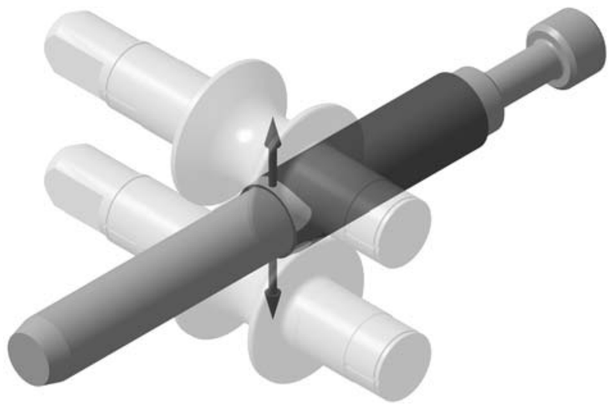

Fig. 4

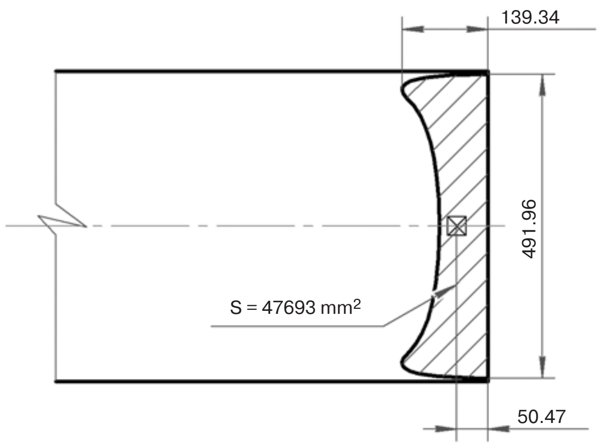

Fig. 5

Special attention should be paid to the fact that upon the condition of the same roll boring diameter as in MPM mill, the shell having diameter of 570 mm, can not enter the inter-roll gap (ref. fig. 2 — a circle shaded in dark grey). The maximum shell diameter which can be used for the three-high scheme in "ideal" option is 520 mm only.

This make us understand that with the same diameter of the mandrel which is used in operation, three-high scheme has a significant limitation of wall reduction in comparison with two-high. This is the first geometrical limitation met by the technologists due to the three-high scheme choice.

The calculations show that the maximum diameter reduction in the three-high scheme in real conditions is equal to 0,05...0,06 of the roll boring diameter, and 0,12...0,13 of the same diameter for the two-high scheme. It follows thence, that the two-high scheme maximum possible wall reduction is twice as much in comparison with three-high scheme.

As it was already mentioned earlier, this is the prime reason why the existing schemes of rolling in the plants with mills MPM and PQF can not be compared. The plant with two-high continuous mill has a larger reduction at reeling mill in comparison with plant with PQF. In case of three-high mill, a part of reduction is transferred to the piercing mill, which therefore, has to pierce thin-walled shells.

For the precise comparison of two rolling schemes we will accept maximum possible for PQF stand schedule with real scheme of roll borings (with increased dimension of wall reduction zone): the shell having diameter of 502 — roll boring diameter of 476 mm. Then we should build tentative schemes of the borings of the stands with retained mandrel rolls for both options, design the roll bearing assemblies structure (upon the condition of their equal load carrying capacity) and then carry out a comparative analysis of technological, technical and operational parameters.

MPM mill rolling schedule and roll assembly structure

The tentative scheme of two-high stand roll borings building is shown on Fig. 3. Not going into details we would like to note the following.

On the basis of two-high continuous mills with retained mandrel design experience, the dimension of intense deformation zone is 120^{o} along the mandrel diameter (ref. Fig. 3). Then after definite calculations we defined roll max. diameter equal to 940 mm by rims, with possible regrinding up to 850 mm.

Now we can start with metal deformation power parameters in MPM stand calculation. Primarily the calculation will be done without taking into consideration of friction on the mandrel.

Friction force influence on power parameters will be studied separately.

The main parameter for rolling force defining is a contact area of roll with rolled material. The said contact area will be defined by 3D modeling method not taking into account metal spreading in groove (ref. fig. 4 since we stipulated some simplifications earlier).

Horizontal plan of contact area of rolls with rolled metal and the said area dimensions and the point of total force application, is shown on Fig. 5.

During the roll rotation, metal, at the expense of friction forces appearing at the roll contact with metal and metal contact with mandrel difference, is moved in longitudinal direction with speed set by rolling technology. For the rolls rotation speed calculation the specific parameter should be defined. This parameter is called rolling radius. While rolling radius calculation, metal friction on groove lateral walls is taken into consideration as a rule. We are not going to describe this parameter calculation algorithm. In general, rolling radius is larger than roll boring bottom radius by 1/3 of intense deformation zone height (ref. fig. 3). This parameter plays an important role for the further analysis.

Lets remember some geometrical parameters (we will use them for comparison later on):

Contact area length, mm	139,34
Contact area width, mm	491,96
Contact area , mm^2	47693
Distance from point of total force application to roll rotation plane (arm of force), mm	50,47
Rolling radius (ref. fig. 1), mm	278,4

On the basis of obtained geometrical parameters it is possible to calculate power parameters of MPM rolling schedule under analysis (not considering friction forces on mandrel). Calculation results are given below:

Rolling force (per 1roll), t	572
Rolling speed, m/sec	1,2
Rolling torque (per 1roll), t·m	28,9
Rolling power (per 1roll), kW	1219,4
Total power per stand, kW	2438,8

After reception of base values with respect to power parameters, JSC "EZTM" design department developed continuous MPM mill stand roll assembly per set tube (ref. Fig. 6, 7).

Here you can see a conventional continuous mill two-high stand roll assembly structure, comprising the roll itself, two chucks with bearing assemblies and a set of details for fastening. Four-row taper bearing type BT4B 328285 by SKF company, is chosen as a main power unit taking rolling force.

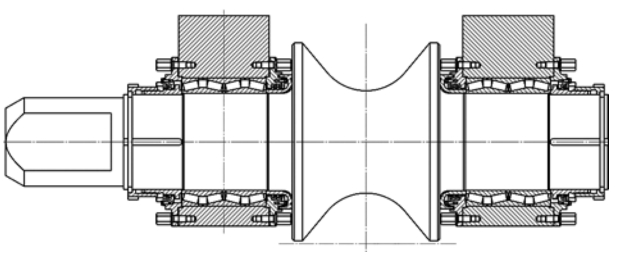

Fig. 6

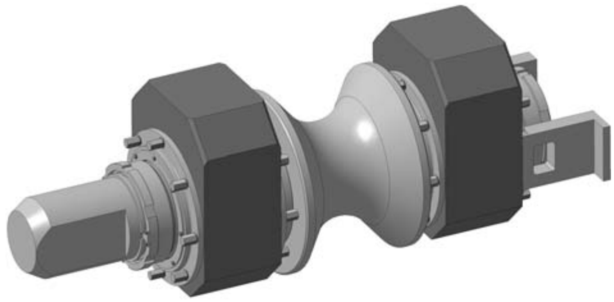

Fig. 7

The following principle worked out within long term experience of similar units design and exploiting was applied at bearing choice: bearing load-carrying capacity should be more or equal to rated force of rolling (however, the force is taken by two bearings).

Under condition of the said principle observation for these structures, there are no troubles with the chosen bearings service life, as a rule.

Main technical characteristics of the said structure are given below:

Roll diameter at rims, mm	850...940
Roll length at rims, mm	700
Bearing type	SKF BT4B 328285
Bearing load-carrying capacity, C dyn, kN	6270000
Roll assembly weight, kg	9000
Roll weight, kg	4700

PQF mill rolling schedule and roll assembly structure

PQF stand rolls boring construction tentative scheme, is shown at Fig. 8.

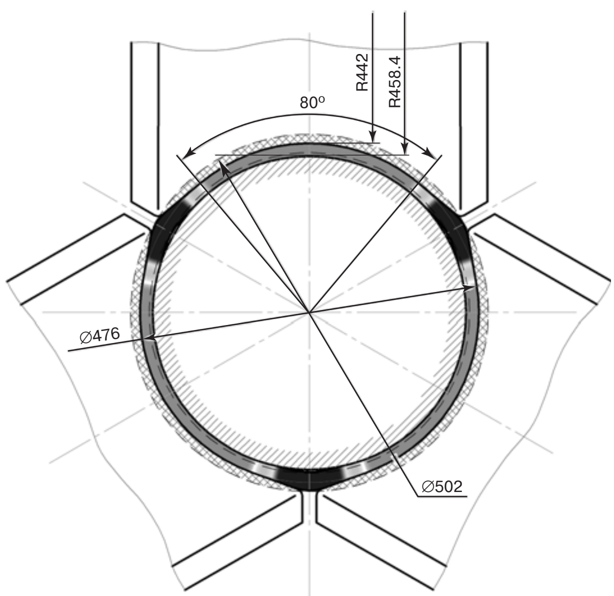

Fig. 8

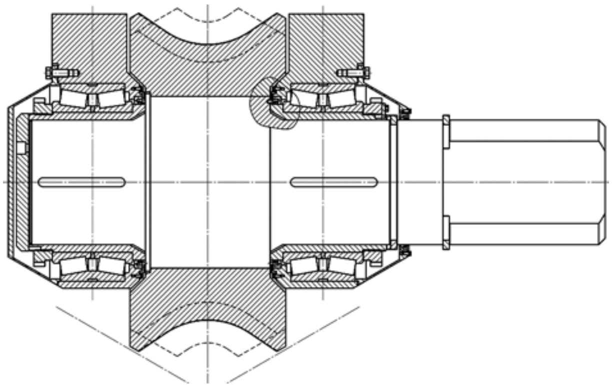

Fig. 9

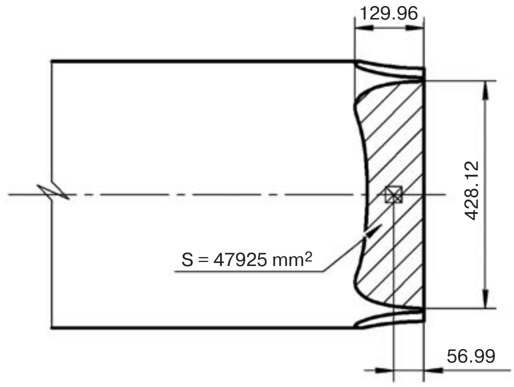

Fig. 12

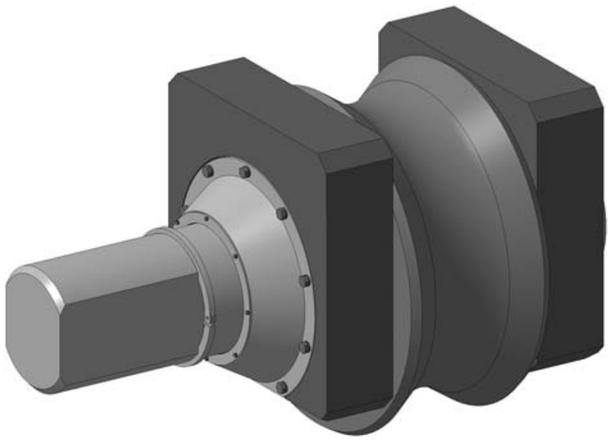

Fig. 10

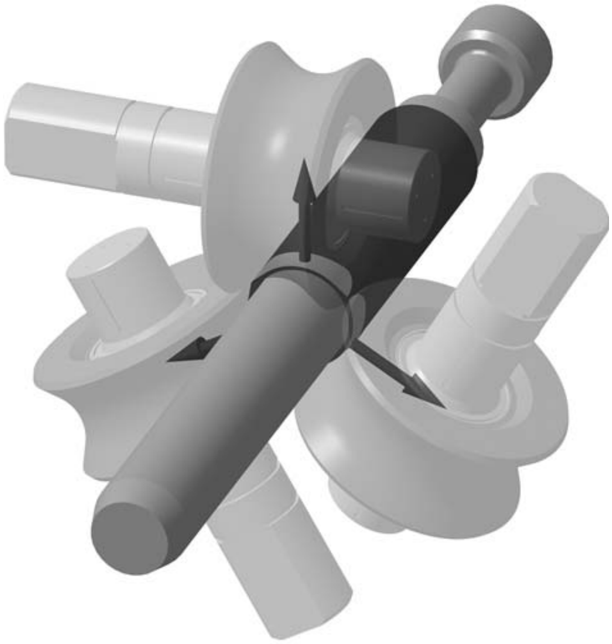

Fig. 11

In common with MPM rolling schedule, here we can find three main deformation zones as well: Intense wall reduction zone, transition zone and metal free spreading zone (or flange zone). Taking into account that wall intense reduction zone is distributed on three rolls, we will take a dimension of this zone equal to 80° for each roll (Fig. 8) in order to provide both variants equivalence.

Conventional rules of roll diameter defining are not suitable for three-high stand since while designing the roll assembly is inserted into the sector located between surfaces coming from the axis of rolling at an angle 120°. That is why PQF stand roll assembly development algorithm is somewhat different in comparison with MPM.

In this case the chosen bearing dimension is a determinant one. Since wall intense reduction zone width is approximately equal to 2/3 of the width of the same zone in MPM case. Then we should choose the bearing having load-carrying capacity equal to 2/3 of MPM roll bearing assembly load carrying capacity. Two-row bearing type BT2B 332176A by SKF company, is chosen as a main power unit taking rolling force.

On the basis of limitations chosen earlier, JSC "EZTM" specialists designed PQF stand roll assembly (Fig. 9, 10) taking into consideration the possibility of roll regrinding to the same size range as MPM roll (ref. earlier).

Please note, that in this case at roll boring diameter decrease for the rolled tube, slot diameter and roll dimensional diameter at rims are increased. Such an effect appears due to insertion of roll, together with bearing assemblies, into the sector at an angle 120°. And this is the second unpleasant fact connected with chosen rolling schedule, and influencing on stand dimensions in the direction of axis of rolling. On the basis of roll dimensions, we can define rolling radius which is an extremely important parameter (as for MPM schedule). In this case its value is equal to 458,4 mm (Fig. 3).

Now we can start with power parameters, of the designed PQF stand, calculation, without taking into account metal friction force on the mandrel as well. As in the case of MPM, the main parameter of rolling force defining, is a contact area of roll with rolled metal. As well as in the previous case, we will define the indicated area by means of 3D modeling method , not considering metal spreading in the groove.

The contact areas of rolled metal with rolls position and rolling forces taken by roll bearing assemblies direction are shown on Fig. 11 .

Horizontal plan of contact area of rolls with rolled metal in PQF stand and the said area dimensions and the point of total force application, is shown on Fig. 12.

Let us fix some geometrical and technical parameters for further comparison:

Contact area length, mm	129,96
Contact area width, mm	428,12
Contact area, mm^2	47925
Distance from point of total force application to roll rotation plane (arm of force), mm	56,99
Rolling radius (ref. fig. 8), mm	458,4
Roll assembly weight, kg	6400
Roll weight, kg	4000

Please note that PQF stand roll contact area with rolled metal is actually equal to the same area in MPM case.

On the basis of obtained geometrical parameters it is possible to calculate power parameters in PQF stand (not considering friction forces on mandrel). Calculation results are given below:

Rolling force (per 1 roll), t	575
Rolling speed, m/sec	1,2
Rolling torque (per 1 roll), t·m	32,8
Rolling power (per 1 roll), kW	840,3
Total power per stand, kW	2521

The parameters to be paid attention at in comparison with MPM rolling schedule are marked with exclamation sign.

Thus, we built one-valued rolling schedules for both options and tried to design equally loaded roll assemblies.

Metal friction forces on mandrel influence on power parameters

The above given calculations, as we already mentioned before, are made without taking into metal friction forces on mandrel and do not provide complete understanding of power parameters for each schedule.

Now we are going to study the rolling schedule in continuous mill on retained mandrel. Lets take up, that mandrel traveling speed is less than metal traveling speed, that is why the roll at rotation will overcome not only metal deformation force, but also metal friction force on the mandrel.

Let's take metal friction on mandrel factor equal to 0,1 (actually it is somewhat below). The rolling radius for both schedules is taken as an arm of friction force to calculate friction torque. For the comparison we will make a direct calculation of friction forces influence on power parameters in one separate stand, but it should be noted that actually the situation is more complex as it is necessary to consider metal stress between the stands and some other factors. The calculation results are given in the next section.

Comparative analysis of power parameters

To make the comparison more obvious, the calculation results are fixed in common table.

Name	MPM	PQF	PQF/ MPM %
Metal deformation analysis			
Contact area per one roll, mm^2	47693	47925	100
Total contact area per stand, mm^2	95386	143775	150
Arm of force, mm	50,47	56,99	113
Rolling radius, mm	278,4	458,4	165
Rolling force, t	572	575	100
Rolling torque, txm	28,9	32,8	113
Rolling speed, m/sec	1,2	1,2	
Rolls rotary speed, rpm	41,16	25	61
Rolling power per roll, kW	1219,4	840,3	
Total power per stand, kW	2438,8	2521	103
Friction forces influence analysis			
Metal friction on mandrel factor	0,1	0,1	
Friction force, t	57,2	57,5	100
Friction torque, txm	15,93	26,36	165
Friction power (per 1 roll),kW	672,6	675,9	100
Total friction power per stand, kW	1345,2	2027,7	151
Summarized information			
Total torque per roll, t×m	44,83	59,16	132
Total power per roll, kW	1892	1516,2	80
Total power per stand, kW	3784	4548,6	120
Bearing type SKF	BT4B 328285	BT2B 332176A	
Dynamic load rating of the bearing, t	627	440	70
Equivalent load at bearing , t	287,6	289	100
Design life, hour	5440	2707	50

To crown it all we should carry out comparative analysis of two schedules under condition of the same result with respect to deformation parameters.

The first thing to be paid attention at, is that both schedules have the same rolling force on roll. This resulted from the actually equal contact area of roll with rolled metal. Such correlation came out of three-high rolling schedule constructional features, and which has bearing assemblies installed in the sector of planes, located at an angle 120^o with respect to axis of rolling. As a result we had to increase roll working diameter artificially, to place the bearings with sufficient (at first thought) load carrying capacity. Roll diameter constructional increase led to the contact area elongation. In this connection we got equal areas. Thereat, arm of resultant force increase in PQF rolling schedule led to increased rolling force on roll in comparison with MPM schedule.

In spite of the above mentioned, the calculation of rolling power required to overcome metal deformation resistance, showed actually equal figures. This is a quite predictable result, showing that we chose rolling schedules with close deformation parameters. Insignificant excess in PQF schedule means nothing: Actually equal work is spent at the same deformation.

However, analyzing the friction forces influence in both rolling schedules we can see completely opposite result. As it is shown in Table 1, metal friction force on mandrel is actually the same in both schedules (the same rolling force), friction torque in PQF schedule is significantly higher than the same in MPM schedule (PQF roll diameter is larger than MPM roll diameter). The power, spent to overcome friction force per each roll, is the same in both cases, however in PQF case, the work is performed by three rolls, not two as in MPM schedule. Thus in PQF schedule occurs an additional friction surface, which finally influence on the power consumed to overcome these forces, greatly. The indicated power at recalculation for stand is half as much again. In addition to this, considering the fact that the rolling is performed on the retained mandrel, rack mechanism controlling the mandrel transfer while tube rolling in PQF mill, should take the force half as much again as well in comparison with the same in MPM mill. The said mechanism electric drive capacity will be increased correspondingly.

Thus, the analysis of two rolling schedules, with same metal deformation on the retained mandrel, shows the following (ref. Table):

— Total torque, taken PQF stand roll is tentatively by 30% more than in MPM stand.

— Total rolling power , consumed by the stand in PQF mill, is by 20 % more than in MPM mill;

— Rack retaining mechanism electric drive installed capacity in PQF mill is tentatively by 50 % more than in MPM mill;

— Design life of PQF stand roll bearing assemblies is actually twice as little than in MPM stand.

In other words, PQF rolling schedule efficiency factor is significantly less in comparison with MPM rolling schedule. To obtain one and the same result PQF mill will spend more energy than MPM mill. PQF mill maintenance will require much more expenses than for MPM mill maintenance.

PQF stand roll bearing assemblies location in the sector of planes, installed at an angle 120^{o} with respect to rolling axis, and as a result — artificial increase of roll diameter, leads to the increase of rolling forces and torques.

Moreover , in the stand drive and mandrel transfer rack mechanism line it is required to have equipment with higher load carrying capacity to provide higher rolling torques on roll and higher mandrel retaining forces, i. e. higher start capital costs...

It is worth to be mentioned that JSC "EZTM" specialists carried out the analysis of the above presented PQF mill roll assembly structure both as in the direction of roll diameter decrease as well as in the direction of bearing assemblies increase, to prolong their service life. In the first case the bearings service life decreased significantly (right down to critical load carrying capacity), in second case the contact area of roll with rolled material was increased, and power parameters of rolling was correspondingly and unreasonably increased. The specialists came to the conclusion that the given version of PQF stand roll assembly is an optimum for this case of comparison.

Tool wearing

The costs connected with the rolling tool wearing is a significant expense item of tube products production cost.

Being guided by the above made calculations, our attention should be paid on the following: roll wearing in the PQF stand will be by all means less in comparison with MPM roll due to the minimum difference of the circumferential speeds of the roll on the contact area (even with equal forces of rolling). However, it should be taken into account that here we have three rolls participating in operation, so the absolute value of rolls wearing per stand (as we can expect) will be equal to rolls wearing per MPM stand.

Actually the opposite situation we meet in case of analysis of the expected mandrel wearing. The total contact area of MPM stand rolls in our case is equal to 95386 mm^2 (ref. table), the same area for the PQF stand is equal to 147375 mm^2. We suppose that tentatively the same correlation will be in areas of mandrel contact with metal. Mandrel wearing is proportional to the total contact area with metal and specific pressure. Taking into account that the force of rolling on the rolls in our case is equal for both options, it is essential to expect increased wearing of mandrels in case of PQF mill.

There is no information concerning the PQF mill tool wearing published anywhere.

Products quality characteristics

On the basis of the above, the following deduction can be voiced: To decide upon the increase of capital and additional process and power costs, there are should be serious competitive advantages of PQF finished products in comparison with MPM mill...

So let us carefully study the quality advantages of the tubes manufactured at PQF, announced by the originators.

Before to start estimation of quality characteristics of the products manufactured at the tube rolling plant with continuous multi-stand three-high mill, let us study the following.

Modern tube hot rolling plant contains three groups of rolling equipment. Each group performs own functions and responsible for its own quality factor for finished products :

Piercing group — as a rule, this is a two-high screw rolling piercer, hich pierces continuous round section billet into hollow shell. Namely this technological operation defines main characteristics of finished tube variation in wall thickness. Actually, no one of the further lengthwise rolling mills can improve basic variation in wall thickness, obtained at the piercer.

Reeling group — in our case this is a continuous multi-stand three-high mill. The said equipment performs the reeling of the shell on long retained mandrel up to the required wall thickness. As it was mentioned above, the variation in wall thickness obtained on the piercing mill can not be decreased on the continuous mill. Designing such mill, a special geometrical method is used to obtain various wall thicknesses at one and the same mandrel diameter with the same roll boring. This method will be described in full details later. The mentioned method (both for PQF, and for MPM mills) can only increase the value of variation in wall thickness obtained at the piercer. Moreover, the variation in wall thickness obtained at the extent of the stands adjustment error, temperatures difference along the tube section and length is added to this.

Sizing (reduction) group — this is essentially a multi-stand three-high sizing mill (or reducing-stretching) mill. This equipment carries out the sizing (or reduction) of tubes with respect to outer diameter, and correspondingly, responsible for the tube diameter accuracy. Though the basic variation in wall thickness got during the shell piercing can not be actually corrected at the said equipment.

Tube diameter tolerance limits double reduction announced by PQF originators can not be anyhow connected with reeling mill. As it was already mentioned above, the sizing (or reducing-stretching) group of equipment is responsible for the outer diameter tolerances. Thus, we are not going to study these announcements in this article, as they can hardly correspond to the technological process structure. However, we will carefully study the wall thickness tolerance double reduction as the reeling mill directly influence this parameter.

The following rolling tool geometrical parameters choice system was established for the continuous multi-stand mill. The entire scheme of rolls boring is defined for a precise rolling schedule (billet diameter — shell diameter — rough tube diameter).

Thereat, in the finishing stands rolls borings, one and the same diameter is used. For our example this diameter is equal to 476 mm (ref. fig. 3, 8). The required wall thickness of the finished tube is obtained by means of mandrel diameter matching. However, considering the fact that there are tubes having the wall thicknesses with difference equal to millimeter portions, within the product mix, such a system of required wall thickness getting in its pure version is extremely inefficient. It is quite obvious that this will require to have a huge stock of the mandrels for each wall thickness in the product mix.

To avoid such a high process costs for the rolling toll maintaining the following method is used. The rolls of two last stands of the continuous mill taking participation in the shell wall squeezing are held in the direction to each other around the mandrel so that the distance to the roll boring bottom becomes equal to the required wall thickness t. Two last finishing MPM mill stands roll grooves boring profiles and

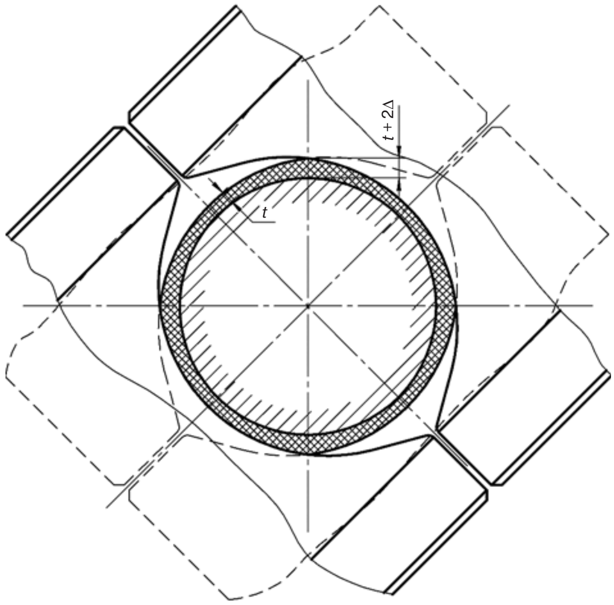

Fig. 13

the profile of the tube which is got as a result of rolling at one and the same mandrel are depicted on Fig. 13.

Generally, t value is taken from the zone of the wall thickness tolerance lower limit. At this in the zones of roll borings profiles crossing zones the thickenings arise $t + 2\Delta$ (ref. fig. 13), tube form becomes a kind of formalized quadrangle with rounded sides. The tube section obtains a form of a circle in the sizing (or reducing-stretching) mill. The tube wall is formed in the reeling mill (as it was explained before). At this the value of roll radial displacement is limited by the wall thickness tolerance. The parameter 2Δ should not exceed the set tolerance.

The similar method is applied in the continuous three-high mill (ref. Fig. 14).

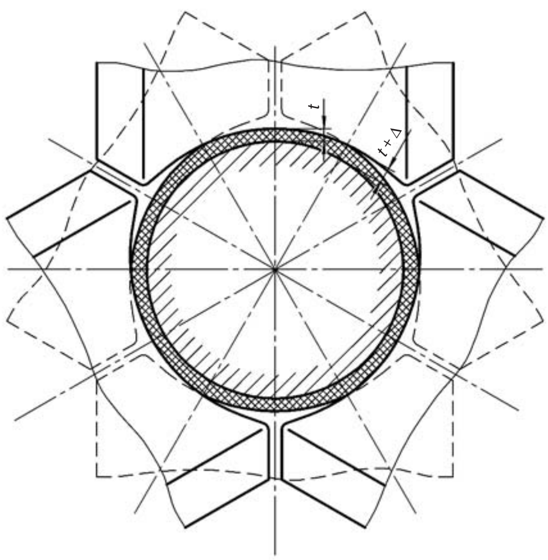

Fig. 14

At this the tube form becomes a kind of formalized hexahedron with rounded sides. At the zones of roll borings profiles crossing zones the thickenings arise as well, but their size is equal to $t + \Delta$. It was geometrically proved that at one and the same radial roll displacement with respect to the mandrel, the variation in wall thickness in the two-high stand of MPM mill is twice as much in comparison with three-high stand of PQF. Here we can see photo camera multilobed diaphragm effect: the more lobes the more round form has the orifice.

In other words: at the same radius of the continuous mill finishing stands rolls boring, same mandrel diameter and same wall thickness tolerance the wider range of tube wall thickness in comparison with MPM can be rolled at PQF, i. e. with the same wall thickness accuracy MPM mill requires to have more sizes of mandrels in comparison with PQF mill.

So, this is the proved geometrical fact on the basis of which the advertising campaign of the continuous three-high mill originators is built. However there is nothing common between this fact and announced wall thickness tolerance double reduction. In theory both mills can provide the same variation in wall thickness, but in practice MPM option will require increased process costs to maintain additional stock of mandrels. Mandrel stock maintaining — is a significant expense item for the products production cost.

In practice there is a following state of things. Process costs for PQF option allow to get smaller tolerance range with respect to tube variation in wall thickness — this parameter reaches the value of ±6...7 %. For MPM mill, the wider tolerance range for the variation in wall thickness equal to ±7...8 % is used, because of the increased process costs for the mandrel stock maintaining. At this it should be noted that the variation in wall thickness is significantly less in comparison with tolerances stipulated by international standards (APM, ASTM, GOST and others). Further decrease of the tolerance for the variation in wall thickness of the produced tubes is limited by the basic variation in wall thickness obtained while shell piercing (±5 %).

However, if the maintaining of the additional mandrel stock causes high process costs at the MPM operation the following processing method can be applied. Let us imagine that (as in our case) the roll boring diameter of PQF mill is 476 mm. At the set variation in wall thickness tolerance, the radial displacement of rolls by 8 mm (4 mm for the radius) for the diameter can be performed at chosen mandrel diameter. Correspondingly, in case of MPM mill with the same roll boring diameter (476 mm), same mandrel diameter and the same tolerance for variation in wall thickness the roll adjustment will be 4 mm for diameter (2 mm for radius). At this approach two standard sizes of the mandrels should be used in MPM mill to provide the set range of rolled walls. However the additional set of rolls of the last two stands with finishing borings of different diameters 476 & 472 mm can be used instead of this. In this case the mandrel stock will be the same as in case of PQF mill. Maintaining of the additional set of two pairs of finishing rolls with different borings does not cause specific difficulties, especially in comparison with additional process costs resulting from the usage of PQF.

Safety and service life

Within a period of 70 years, "Elektrostal heavy engineering works" formed its own school or rolling equipment design. Within this period of time a number of conceptual approaches to the questions of rolling equipment safety and service life were developed and implemented in practice. The basis of the said approaches is constituted by the following points:

— complicated machine complexes modular-assembly design principles;

— task splitting onto a number of independent subtasks and these subtasks mutual influence minimization;

— decrease of a quantity of teams occupied with solving of one task;

— parallel performance of equipment operation and its modules maintenance;

From a point of view of concept the following could be mentioned:

— continuous reeling mill should be considered as a multi-block module comprising several stands fixed on the entire basement — this will increase equipment safety;

— Each stand should have independent mechanical power circuit taking up a force of rolling – this will increase equipment safety as well;

— Power circuit should be compact so that to provide the required rigidity of the stand – this will enable to increase an accuracy of rolling;

— Primary adjustment of each stand should be done out of the mill on a separate bench. So the stand should be installed into the line being completely adjusted and rested on the base surfaces so that the axis of rolling is set up automatically — this will allow to reduce the mill adjustment auxiliary time and increase its capacity;

— Power adjusting elements should preferably have mechanical principle of operation. Hydraulics implementation is allowable only as a kind of option to carry out additional technological tasks while metal rolling — this will increase equipment operation safety and will allow to reduce the costs connected with mill unscheduled shutdowns;

— Mill change from one standard size to the other should be done by means of stands changing, stands maintenance and repair should be done out of the mill line — this will allow to reduce the costs connected with stands power elements maintenance as the mentioned works will be carried out simultaneously with continuous mill operation;

The failure of the stand or one of its elements will not lead to the entire mill disability since the stand will be simply changed by the other stand. The failure of hydraulics in the power circuit will lead to the disconnection of optional technological capabilities, however the basic rolling scheme will remain the same.

Automation system should be built on the principle of several levels as well and on the different levels independent operation on various levels. The breakdown or failure in the top level system should not influence anyhow on the lower level systems operation.

On the basis of the above principles, JSC EZTM designed and commissioned a number of tube rolling plants with continuous mills, which show safe operation for dozens of years.

From this point of view there are too many questions to the supplied options of PQF mill:

— well-known hydraulic capsule is not a finite and rigid element taking the force of rolling as the finite element is a hydraulic system — obvious decrease of equipment operation safety, failure of any element of the system (sensor, fitting, pipeline) will lead to the entire mill disability;

— cassette does not comprise rigid adjusting circuit, cassettes adjustment for axis of rolling is performed in the mill line according to the basic surfaces — actually "at random", which spends operational time of the mill — actually this is a reduction of the entire plant capacity;

— in case of basic surfaces or power circuit mechanical wearing, the adjustment of axis of rolling is interrupted — this influences on products quality in negative way;

— the entire power circuit of the mill has rather large dimensions. This influence on the structure rigidity in negative way, the circuit spring should be taken into account at the rolling — accompanied by the previous aspects, eventually it could spoil the quality of the manufactured products;

— the breakdown of any element of the entire power circuit will lead to the whole mill shutdown, the maintenance and repair of the elements should be done directly in the mill line — obvious equipment operation safety reduction, decrease in capacity and as a result increased costs for equipment maintenance;

— power hydraulics operation totally depends on the automated system, any failure of the program will cause total disability of the mill — this means mill operation safety decrease and capacity reduction as a result;

— the number of elements in the drive line significantly exceeds the same in the drive line of MPM — from the point of view of probability theory, PQF mill safety level is significantly lower in comparison with MPM mill.

PQF mill design principles greatly differ from the principles of rolling equipment designing used by JSC "EZTM", and in our opinion, can be considered rather controversial from the point of view of safety and service life.

Conclusion

After the complex of engineering and research works, JSC "EZTM" specialists came to the conclusion that both units with different types of reeling mills (PQF & MPM) can achieve the same figures with respect to the rolled tubes accuracy. The only difference is concluded in capital and process costs. In same conditions PQF scheme significantly loses in part of process costs.

In addition to the above no one serious competitive advantage of PQF mill products was found. This fact is actually proved: you won't be able to find in the market a tube which was not sold by the reason of its manufacture at MPM mill.

The main purpose of each enterprise is money earning. That is why any new technological achievement should be estimated from the point of view of process costs.

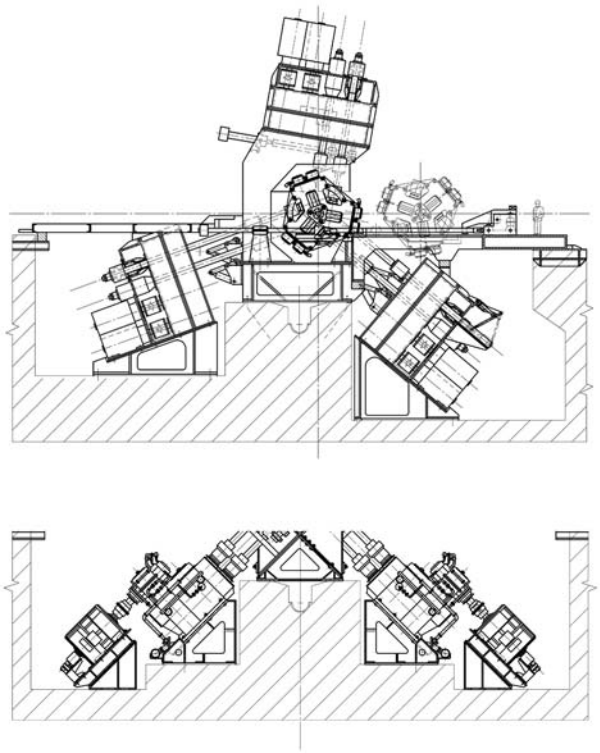

Fig. 15

To compare own competitiveness in Global economic crisis conditions and impeding energy resources crisis, metal manufacturers should increase the efficiency of their production facilities using. This can be reached by means of optimization and efficiency promotion of existing processes and technological chain in the whole. The most burning issue today is connected with energy — and resource saving technologies and correspondent technical solutions.

Then if the additional money can be paid for ±1% of variation in wall thickness tolerance on the market and the tube plant Customer can see the steady trend to price advance with respect to such products on the market within a payback time, so the only recommendation that we can give is to build three-high rolling mill.

But in case the market can not pay for the additional costs connected with tube manufacture on such mills, the Customer should pay his special attention on MPM technology. This is especially topical for tubes having diameter above 270 mm.

Anyway German colleagues should be thanked for the courage that they demonstrated to implement three-high technology in the continuous multi-stand mill. Global tube rolling community got an unpriced (though sometimes rather controversial) experience.

JSC "EZTM" posses own "Know-How" both as for the option of tube rolling plant with three-high reeling mill (PQF analogue), and for the option with two-high reeling mill (New MPM) (Fig. 15). JSC "EZTM" specialists used their experience of analogous equipment designing and tried to reduce the process costs to a minimum in their solutions according to the above given principles of rolling equipment designing.

We ere ready to customize these solutions at any place of the World and hope that the above information will help our eventual Customers in their business-plans developments for the similar objects construction.

Automatic drive systems of transport-technological complexes

B. N. Koutsenko, I. N. Beloglazov, O. A. Dulneva, A. I. Mikheyev, M. A. Perfilova
Saint Petersburg State Mining Institute (Technical University)

The increase in ironworks production has determined the necessity of introduction of continuous production lines and up-to-date automatic transport-technological complexes ATTC. To secure improved reliability of the equipment applied in ATTC, particularly conveyor units, the transition to multi-motor electric drives is taking place to provide more uniform load distribution along the routing of conveyor systems.

The multi-motor electric drive is used when the routing of conveyor systems is very long and complex [1]. Its application facilitates the operation of a conveyor mechanical section providing more equal distribution of moving force along the conveyor route. So, for instance, from the orthographic epure moving force it is obvious that at the moment of transition from a single-motor electric drive to a twin-motor one (provided that the load is equally distributed between electric motors) the maximum pull is reduced by half. The equal load distribution between motors is one of the basic problems to be solved in the course of conveyor system multi-motor drive designing and operation (Fig. 1). The conventional approach to solving the problem is application of uniform motors with similar nominal parameters and an appropriate location of motors in the conveyor system [2]. However, considering motor technological parameter spread, as well as a nonoptimal selection of motor location caused by lack of space in shop-floor conditions, calculating errors, etc., as a rule it is impossible to achieve uniform motor operation in multi-motor drives of conveyor units only due to the above-mentioned measures. As the investigations conducted on five-motor conveyor PK-1 of "Kirovsky zavod" industrial association have shown [3], total active power ranged within 20 % (from 8 to 10 kW) during operation time, yet each motor power ranged within wider variation limits. Load ratio of two motors out of 5 during the whole testing period (4 days) made 20–50 % from the other 3 motors loading. Similar load distribution results in the need for overmotoring of drive and causes mechanical failures, decrease in motor efficiency and power factor, etc. It is necessary to create a special system of automatic load control to balance load in individual motors. Induction motors (IM) with phase-wound rotor, IM with thyristor control, DC machines, a drive with variable reduction gearbox ratio and some other drive types can be used in the multi-motor drive with automatic load balancing of individual motors, but the direct-current drive has not been considered on the grounds of drive reliability.

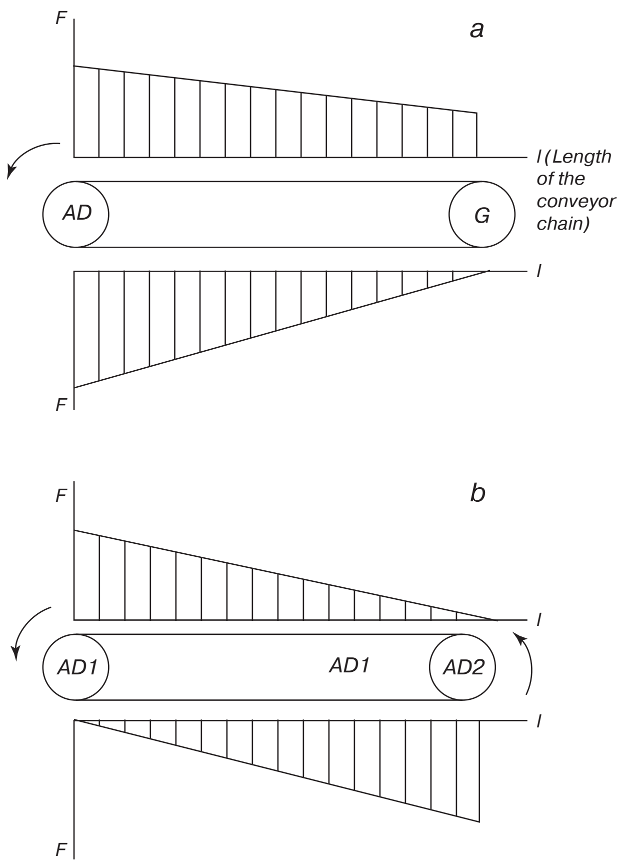

Fig. 1. Moving force distribution diagram (*G* — Idle Gear)

The given paper presents the results obtained when developing the following types of conveyor electric drives, viz. the electric drive with IM use with a squirrel-cage rotor and variable parameters [4], the electric drive with an induction squirrel-cage motor and differential speed reduction device controlled by DC machines [3, 5, 6] .