

# The research on the levelling process of thick slabs based on the electric motor parameters monitoring

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**Abstract.** For the leveling machines in conditions of a small batch production which is typical for manufacturing sheets of non-ferrous alloys, in particular, titanium, the rollers heating is very influential. In order to expand the technological possibilities of the main equipment in non-stationary thermal working conditions of rollers that is an actual new scientific problem the experimental study of the loading in the hot leveling of slabs made from hardly-deformed titanium alloys was carried out on the 9-roll leveling machine. To achieve this goal the methodology of the complex experimental study of the actual loading definition of the leveling machine drive was developed. The experimental study was carried out for alloys Ti6Al4V (Vt-6s) and PT-3V with the initial heating temperature of the rolled product from 750 to 850°C. The slab leveling process was logged for slabs with the thickness from 20 to 68 mm, the width from 985 to 1720 mm by the number of passes through the leveling machine from 2 to 8. The treatment and analysis of experimental data was conducted on the basis of which the summary of permissibility of assortment expansion of leveling slabs has been formulated.

## 1. Introduction

The technological operation of leveling is obligatory in the sheet and slab production both for ferrous and non-ferrous alloys. In this operation the elimination of the number of geometrical flaws of rolled sheet product (such as rippling, camber, crescent) those occurs in the hot rolling process and subsequent cooling is taking places [1–3]. The main equipment to execute the leveling process is the roll-type leveling machines which provide the defect elimination by reversed bending in cylindrical rolls with staggered order of its disposal along the longwise axis of leveled slabs or sheets. The roll-type leveling machines with a number of rolls from 7 to 11 are applied to level the thick slabs while to level the especially thick slabs are usually using the machines with 7 or 9 rolls.

The leveling of all produced assortments of sheets and slabs is likely to be executed on the special roll-type leveling machines with appropriate selection of the roll's diameter, step and number [!]. It is settled relatively simply in the conditions of mass and large-scale production of rolled sheets. In the leveling of slabs and sheets in the conditions of low-batch size production which is most common for the enterprises those specialize on the production of sheets made of highly-alloyed steels and non-ferrous alloys (in particular, titanium alloys) the application of deeply-oriented specialization of leveling machines isn't rational [4, 5]. Therefore, for such kind of the production the leveling of all assortments is carried out on the restricted number of leveling machines with wide range of treated sheet sizes, frequently beyond the bounds allowed by the equipment's technical characteristics.



For the leveling machines used for the sheet leveling in conditions of a small batch production which is a typical situation for enterprises manufacturing sheets for special steel or non-ferrous alloys, in particular, titanium alloys, the rollers heating is very influential. In this kind of production it is very complicated to accomplish the qualified adjustment of the leveling machine on the basis of production data due to the unstable temperature working conditions of rollers, which means that it is necessary to carry out the leveling with a constant tuning or an additional leveling of the product. In the large-scale and mass serial production of sheets the indicated factors of instability make an impact only in periods of the beginning of the sheet batch leveling and further the thermal mode of the rollers work stabilizes [6, 7].

## **2. The experimental measurements of the levelling machine's engine loading**

On the purpose to justify the possibilities to expand the technological capabilities of the main equipment in non-stationary thermal working conditions of rollers that is an actual new scientific problem the experimental study of the loading in the hot leveling of slabs made from hardly-deformed titanium alloys was carried out on the 9-roll leveling machine.

As the object of the research the 9-roll leveling machine places in the sheet-rolling workshop on the area of heat treatment and leveling of the titanium alloy slabs was considered. The roll-type leveling machine has 7 working rolls with the barrel diameter 400 mm and barrel length 2000 mm each of whom opposite supported by backup rolls 450 mm in diameter. On the input and the output of the leveling machine additional 2 rolls have been installed (without backup rolls) 453 mm in diameter. All rolls set up with the standard step 460 mm. The rolls drive is group-type that includes the direct current electric motor with the nominal power 95 kW and the nominal rotary speed 500 min<sup>-1</sup> via hybrid gear box, the pinion stand at the same time, with gear ratio 42.17 and nine universal joints assembled on the bearing coupling (Figure 1).

Taking into account that the design of this leveling machine doesn't imply the probing placement (load cells) the most effective and reliable method to define the summarized technological loading is to control the process by the main drive's electric motor current parameters. At the same time, to increase the reliability of measurements it is desirable to control the technological loading in alternative way; in particular, there was a solution to periodically measure the torque on the joints by the tensiometric method [8].

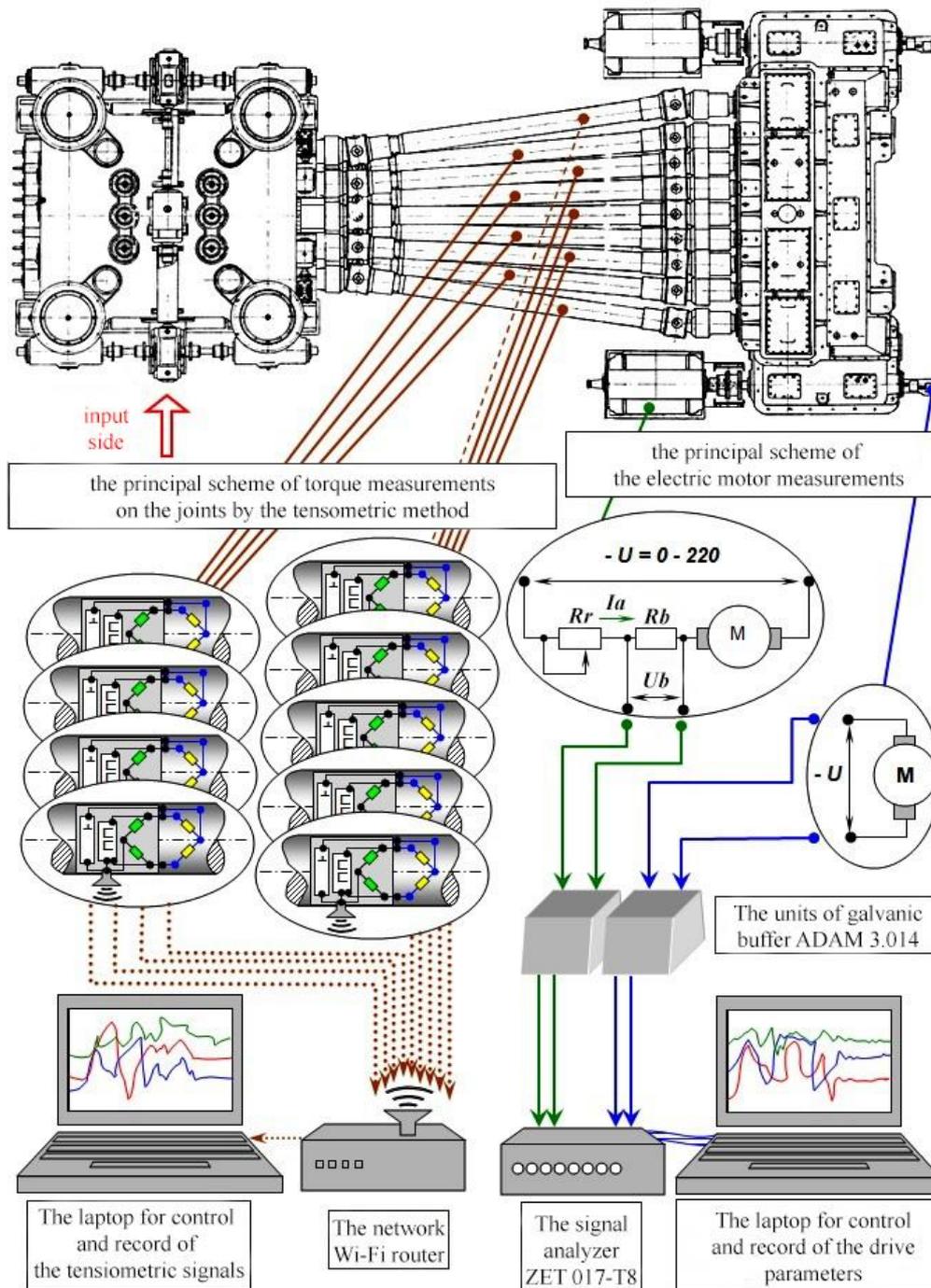
The methodology of the experimental research of the virtual loading of the leveling machine's main drive anticipated the record on the next values with the usage of the hardware:

- the current of the armature circuit of the rolls drive's electric motor;
- the rotary speed of the rolls drive's electric motor rotor;
- the torque transmitted by each of the rolls drive's joint.

According to the developed methodology of the experimental research additionally for each batch or series of workpieces it is necessary to log the number of the common parameters in the table format, such as: an alloy grade, a type of a technological operation (leveling, annealing with leveling, etc.), a thickness, width and length of a leveled slab, a temperature and duration of an initial heating, a leveling scheme, an upper beam movement, special conditions of the leveling.

For practical realization of the developed methodology the principle scheme to measure and record the loading parameters appearing in the main line of the leveling machine LPM-22 during the leveling was stated (Figure 1). To record the parameters 2 in-parallel schemes of measurement were used:

- to log the electric drive parameters;
- to log the signals of the torque detectors, aka the wireless system of data communication.



**Figure 1.** The principle scheme of technological loading measurements during titanium slab leveling on the 9-roll leveling machines.

The system for measurement and record of the electric drive parameters designed on the basis of the signal analyzer ZET 017-T8 working in the mode of multi-channel oscilloscope together with the laptop (figure 1). All measured parameters with a usage of built-in the signal analyzer's hybrid converter and amplifier were being converted in the digital form and logged by the computer with simultaneous visualization on the laptop screen. The record of the armature circuit current and rotary speed of the rolls electric drive's rotor was carried out from control instrumentation (ammeters) by the

connection to the relevant points of the electric drive's control cabinets. The connection to the signal analyzer ZET017-T8 was executed via the units of galvanic buffer ADAM 3.014. To evaluate the current loading dynamics of the main electric motor of the leveling machine and the rotary speed the sampling time step of the logged signal was 0.02 s, what corresponds to the sampling rate 50 Hz.

The experimental research was conducted for alloys Ti6Al4V and PT-3V with the initial temperature of a slab heating 750–850 °C with the upper beam movement relative to the leveled slabs within limits of 3.0–11.0 mm. The leveling process was logged for the slabs with the thickness 20–68 mm, the width 985–1720 mm with the number of passes through the machine from 2 to 8.

In the course of the research the variation of the leveled slabs overstepped the limits set by the leveling machine's technical characteristics mainly by the slab thickness. Thus, the restricted level for this machine is no bigger than 22 mm in thickness and 1800 mm in width with the flow stress of the metal by the leveling temperature no more than 500 MPa with simultaneous combination of these parameters. Therefore, the permissibility of technological possibilities expansion for the 9-roll leveling machine was experimentally checked out in the titanium slab leveling.

### 3. The processing of the experimental data

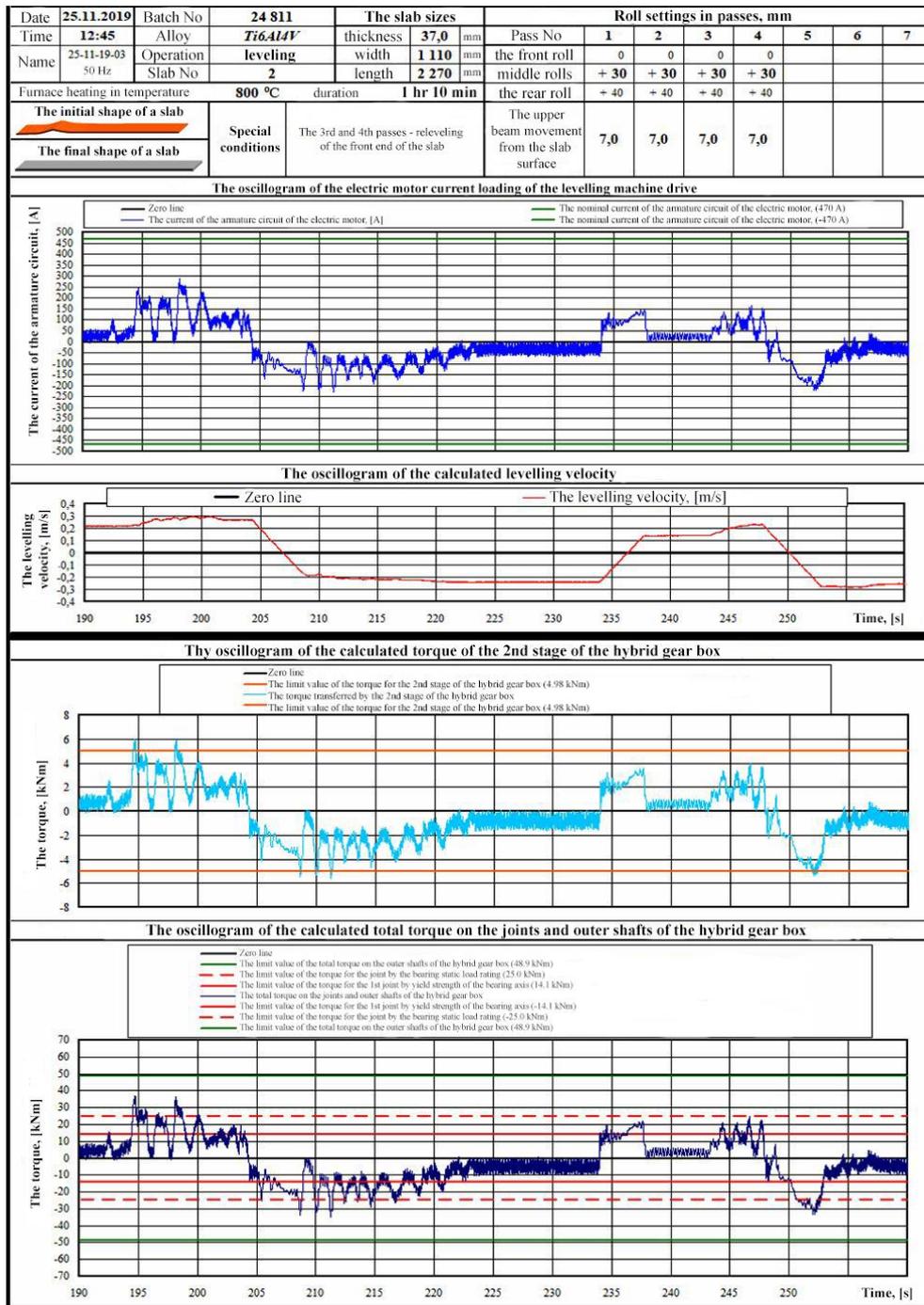
Received in the course of the experimental research digital data array was treated in order to obtain a more convenient form of the result visualization (the example of the treatment is shown in figure 2). After the treatment the analysis of the results was carried out which lead to the next findings:

- the torque on the joints defined with the usage of resistance strain gages and calculated thought the rolls drive electric motor current are in agreement with each other. This allows to define the loading of the mechanical transmission of the leveling machine thought the calculated values of the torque measured on the constantly logged value of the armature circuit current;
- the power parameters of the levelling process for slabs with minor, visually indistinguishable defects of the flatness deviation stay stable enough within the levelled slabs batch. The presence on the initial slabs of considerable, visually noticeable defects of flatness deviations in the form of hollows and bulges are lead to the increase of the technological loading up to 50–70% of the level of the power parameters those take place in the process of non-defect slabs levelling.

The electric motor, by means of which the drive of the leveling machine is operating, is working in the normal mode. The values of the armature circuit currents for all routes of the leveling don't exceed the nominal value of the current 470 A. In the leveling of the slabs the actual values of current of the technological loading are 40–95% of the nominal value and in the leveling of the typical assortment – 15–40 %. Thus, there is no danger of overloading or overheating the electric motor windings.

The dynamic loads during acceleration and slowdown of the main engine of the leveling machine are acting only on the insignificant part of the leveled sheet length (Figure 2), which allows to evaluate the energy-power parameters of the leveling process on the prolonged phase of realization of the technological process with the constant velocity.

The most loaded of the gearing of the hybrid gear box (pinion stand) is the 2<sup>nd</sup> reducing stage by the contact strength of driven gear cog. In the period of the peak values of the torque occurrence those were registered in the course of the research (in the leveling of the slabs with thickness 61.0 and 68.0 mm) there was the overloading of the 2<sup>nd</sup> stage of the hybrid gear box by the contact strength criterion on 90–120%. Another peak resulted in the overloading but on the lower level (70–40%) which was noticed in the slabs leveling with thickness 58.2, 47.1 and 39.0 mm. During the leveling of the thickest slab (68.0 and 61.0 mm) the average level of the loading came to 80–90% of the limit values. In case of the leveling of the slabs with thickness from 39.0 mm to 47.2 mm the average level of loads with regards to the width of the slabs can reach 50–80% of the limit values.



**Figure 2.** The example of the experimental data treatment for the hot leveling process of the titanium slabs on the 9-roll leveling machine.

During execution of the slabs leveling with thickness from 37.0 mm to 20.4 mm the average values of contact stresses in cogs of the driven gear of the 2<sup>nd</sup> reducing stage would be up to 35–50% of the permissible values.

The statistical significance of obtained results is sufficient because the gauging was conducted both for circuits of measurements of current signals of the electric motor by the direct method and though the tensiometric sensors with the usage of the calibration beam of equal resistance. Moreover, to register the current parameters of electric motor the certified special equipment was used.

The dissipation of experimental data within one batch of slabs considering low-batch nature of the production and instability of the thermal working conditions of rollers achieve 20–25%. Besides, the highest loading was observed in the leveling of the first slabs in batch.

The weakest component of the leveling machine LPM-22, taking into account non-uniformity of the torque distribution, is the joints of the roll drive. For all recorded leveling routes the exceeding of the limit value of the torque was registered by the criterion of the joint's bearing axis strength. The peak loads mentioned above in the process of the thickest slabs leveling also lead to overloading the joint's hinge bearing itself. The rational way for the solution of the problem of the joint's carrying capacity is seen as the improvement of the hinge unit.

Considering all the aspects of conducted research it is possible to make the conclusion that there is an opportunity to expand the technological possibility of the 9-roll leveling machine in comparison with the manufacturer's technical characteristics.

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