



## THE EXPERIMENTAL INVESTIGATIONS AND MODELLING OF TRACK WORK WITH THE USE OF TAMPING MACHINE'S DIAGNOSTIC INFORMATIONS

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### Abstract

The paper presents research program conducted in the Railway Engineering Department of Gdansk University of Technology which an idea concerning using the tamping machine to research in the range of track's diagnostic. The research has been focused on two issues concerning to CWR track, it means on the axial forces occurred in the rails as the lateral resistance of track grate which is mainly dependent on the state of ballast's stabilization. The subject matter is still current therefore the effective methods of estimation these variables in an operated rail track are still developed.

In the article author characterizes the main theoretical assumptions which stated the base for developing the methodology of the research conducting in the operated tracks in a stationary position as well as during the standard tamping machine's work. The course of carried out experiments has been described. Also the paper presents a discussion of the obtained results which supported previously defined hypothesis as well as allowed author to start a next phase of the program related to developing the mathematical model of the track grate. The drawn conclusions are pointing at the advisability of further developing of proposed methods of measurements and calculations. Therefore the final part of the paper outlines the continuation of this research. The further program will be mainly aimed on the track stability issue. The results of proposed further studies in order to have an useful character in practice, should include - in addition to an extended analytical model - the methodology for determining the quantitative and qualitative characteristics relating to the modeled phenomena – occurring during operation of the tracks.

*Keywords: tamping machine, longitudinal thermal forces, lateral resistance*

### 1 Introduction

From the beginning of applying the continuous welded rail track it is well known that we lack an effective method to estimate the thermal forces in rails. The 80's were a decade of searching for such a method, mainly in the USA [1]; in 90' the searching got the significant escalation and it is still continued in current decade [2], [3], [4], [5]. So far it has not been success to work out the method to measure directly the longitudinal forces, fully adjusted to the conditions of the maintenance practice.

And monitoring the state of the lateral resistance, as the main factor to secure the track's stability, has been known to be extremely difficult. Non-destructive methods, which do not interfere with the stabilised construction of rail track, did not bring so far satisfactory results.

Therefore the most reliable method of learning about the resistance occurring in the operated rail tracks is a direct measurement of applied force and a corresponding displacement [6], [7]. Unfortunately, this kind of research causes the changes of a ballast structure. Since the mid 90' in the Department of Railway Engineering of the University of Technology in Gdansk, the possibility of using a tamping machine in rail track diagnostic has been researched. The main goal of the above research has been related to the work of tamping machine in order to find a method to determine a state of longitudinal forces that occur in rails of CWR track [8]. During the investigation an idea appeared to conduct a parallel research of a lateral resistance in the rail track structure [9]. The determination of longitudinal forces, as well as the lateral resistance in the rail track structure have been decided to be combined with a technology process, where the lateral dislocations of a track grate occur in a work that was planned and necessary to perform. Often such work occurs during the regular activities connected with a geometrical regulation of the rail track by the use of tamping machine.

## 2 Idea of determining the longitudinal forces in rails

### 2.1 Adoption of measurement the curvature as a base of the investigation

At the University of Technology in Gdansk (Poland) a proper research program has been worked out. They were referenced to the American and British researches [1, 4]. The execution of the research pointed to the possibility of using tamping machine for purely diagnostic purposes, especially to conclude about the longitudinal force on the base of the measurement of the level of curvature with the various values of lateral track grate dislocation [8]. It has been decided to estimation the curvature's value by the use of a proper pointer. The method based on the measurement the dislocations of the track grate in three points close the lifting-slewing unit, the line of the reference to be a frame of the tamping machine.

### 2.2 Experimental tests

Project executors have been driven by the idea of constructing the measuring apparatus, which could cooperate with the tamping machine non-invasive, and also could be resistant to the external influences occurring during work of actual machine [8]. Finally the solution which does not need any interferences into the machine's construction as well as gives the measurement's set a mobile character has been proposed. The verification of the measurement apparatus in case of lateral displacements has been performed on a stationary test position as well as during the work of tamping machine. During the verification process signal from a middle sensor occurred to be very disturbed. The sensor has been placed very close to the lifting-slewing unit. The avoiding of the disturbance and filtration of those signal and bringing out the useful information appeared to be impossible.

That is why during the stationary position tests, the previous displacement sensors were changed by the classic inductive sensors which were working with a CL70-200 amplifier. Additionally, the research program expended with the analysis of the measurement of a state of stress in the piston rods of horizontal hydraulic actuators. This element was added in order to determine the lateral resistance (outlined in p. 3).

Both rails were tensed by the use of the rail tensors in order to apply an assumed axial force level. Several series of the measurement with a various values of axial forces in rails:  $P = 0$ ,  $P = 100$  kN,  $P = 200$  kN i  $P = 300$  kN were successfully executed.

### 2.3 The results of measurement of the axial forces in rails

Proper time signals from inductive sensors after calibration to the distance units allow to show a track slewing in measurement points 1, 2 i 3 on the length of the tamping machine, whereas pointers  $k_2$  show the curvature in the middle measured point (fig. 1).

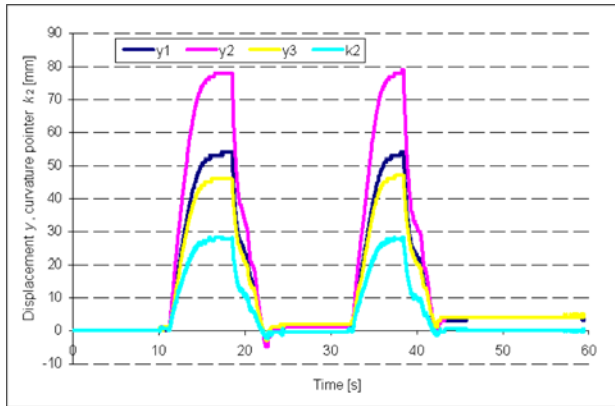


Figure 1 Time signals of displacement  $y$  and curvature pointer  $k_2$  of the rail with the axial force  $P = 200$  kN

The most essential information was provided by the curvature pointer  $k_2$ , which was determined in the position of maximum track displacement -  $y_2$ . The relationship between the curvature pointer and the displacement  $y_2$  designated for various axial force value was showed in figure 2. Once again, as in the previous observations, it was confirmed that the value of curvature directly depends on the state of axial stress in the rails of rail track structure. These relationships could exemplify the monograms, which allowed determining in quite a simple manner the value of axial forces in the rails of cwr track by the measurement of the displacement in three points of the track grate during the tamping machine's standard work.

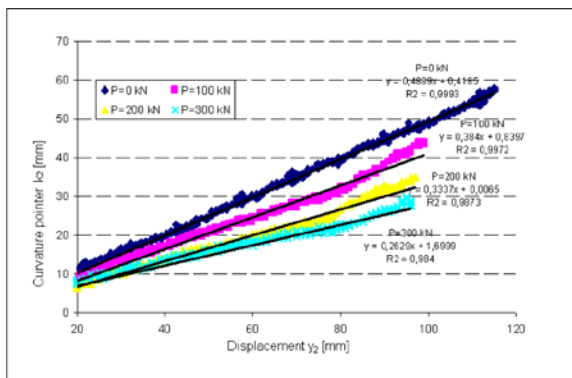


Figure 2 Regression lines of  $k_2 = f(y_2)$  for various value of axial forces in rails

## 3 The concept of determining the lateral resistance of track grate

### 3.1 The methodology of conducted measurements

Apart from the destructive methods analysis, at the Department of Railway Engineering, Gdansk University of Technology, there has been also some research conducted on the non-destructive methods, allowing to determine the stabilisation of track ballast. During the tests that used the tamping machine it was noticed that the measurement of the force in piston rods of horizontal hydraulic actuators, helped to find information about the diverse affect of the ballast bed on the time signal on measure quantity. Therefore it was stated, that the registration of the force by which the tamping machine normally applies the horizontal displacement of the track grate was a right direction in order to work out the method of estimation the lateral resistance in the operated rail track.

The sensors were installed on the surfaces of the piston rods of horizontal hydraulic actuators. The manner of measurement of the track grate's displacements during tests in stationary position is described this article, page 2. In case of the measurements that were conducted during the tamping machine' standard work, the use of sensors that normally work in the mechanical contact with the rail was impossible. That is why it was decided to perform the measurement of displacement by the use of an optical sensor.

The research program included two fundamental stages. The first one was executed in the stationary position. Whereas, the second stage of the research program included experiments conducted during the standard work of the tamping machine. The measurement series enabled to verify the adopted methodology in diverse variants of the actual machine's work. The tests were conducted with the typical technological process of the track adjustment, as well as during the atypical work. The non-standard case described the dislocation of the track measured in several stages.

### 3.2 Adopting a lateral resistance pointer

The time signals of individual measurement cycles were illustrated as the relationship between an applied force  $F$  and lateral displacement of the track grate  $S$ . On the displacement loop, it is possible to see a load and relief phases separately. In the detailed analysis the authors focused on the load phase.

After analysing a large number of results with displacement cycles, the authors stated that the resistance, which the tamping machine encounters during its work, has a nonlinear character. However, the initial phase of the displacement corresponds to the quasi-linear increase of the apply force. In most cases, the beginning of the phase (0-10mm) could be approximated by a linear function.

It was accepted that the lateral resistance pointer could be estimated by the slope of linear characteristic, by the approximation process. The definition of the pointer is illustrated in figure 3.

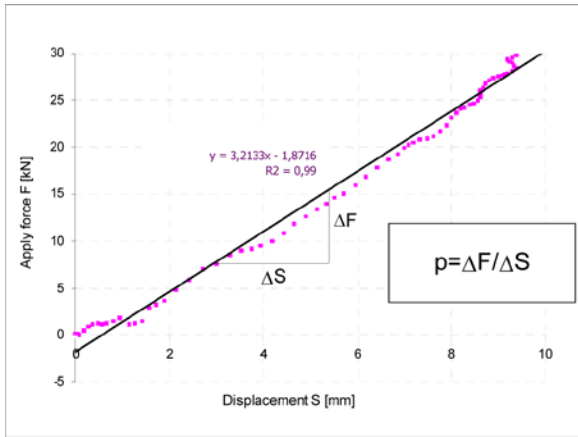


Figure 3 The graphical interpretation of the lateral resistance pointer obtained by the use of measurement with working tamping machine

### 3.3 The susceptibility of the accepted lateral resistance pointer on the state of ballast stabilisation

In order to determine the susceptibility of the adopted pointer on the state of ballast stabilization, the authors analysed the results of the experiment which consisted of the lateral dislocation of the track grate without any lifting, observed in the several passages of tamping machine. Considering the above way the machine works, the first measurement series were to determine the resistance value in the case of stabilised track during the operation process. Figure 4 illustrates in the graphical manner the mean values of the pointer along with the standard deviation in individual series. As expected, the highest value of the resistance is present in the 1st series of measurement carried out in a track with stabilised structure, without any raising. The next series illustrate cases when the main reason of resistance is a friction force occurring between a sleeper's bottom and ballast surface. The influence of a side resistance is much reduced. In the very last series, the sleeper's heads were totally bare in some localisations.

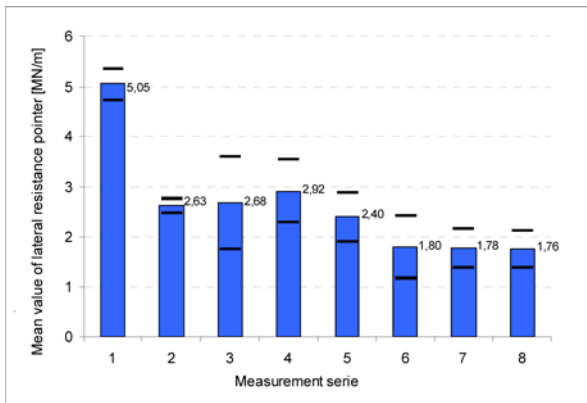


Figure 4 Determined mean values of lateral resistance pointer along with the marked standard deviation for the individual measurement series

The results of carried out tests also point out on the diversity of the resistance on the length of adjusted rail track. The value of lateral resistance could vary significantly on the length of just few dozens of meters.

## 4 Numerical model of investigation phenomenon

For the purpose of obtaining a possibility to generalize the results of investigations carried out by computer simulation, a mathematical model of railway track was proposed for the analysis. Due to a complexity of the system, the authors decided to use the Lagrange energetic method to formulate such a model. The model was worked out for the lumped conservative and dissipative elements [10]. This method makes it possible to work out a set of differential equations of the rail track as a mathematical model from the Euler-Lagrange equation. The generalized coordinates are represented by positions and velocities of free nodes.

Thus the track grate in the process of excited lateral displacement was modeled as a beam of blocked degrees of freedom at its ends. The beam is divided to lumped conservative elements, mass, springs, and dissipative ones, dampers. The interactions between sleepers and the ballast bed, as well as the friction taking place in the ballast, at points of contact between ballast grains, were modeled by using a lumped Kelvin – Voight rheological system and a nonlinear friction function which enabled to simulate the changes of the ballast structure during the track horizontal displacement process. The carried out simulations let the authors calculate the nonlinear characteristics of the ballast resistance. Figure 5 presents an exemplary result of the numerical simulation of the investigated phenomenon.

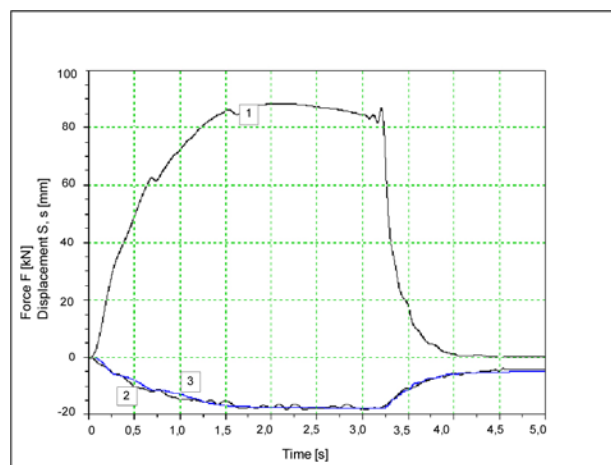


Figure 5 Simulation result: 1 – apply force  $F$  [kN] (from experiment), 2 – displacement  $S$  [mm] (from experiment), 3 – displacement  $s$  [mm] as a simulation's result

## 5 Conclusions

- 1 The results of stationary experiments proved the correctness of the thesis, that there is a clear relationship between the curvature of the rail that occurs in the slewing process with the tamping machine, and the existing state of the stress in rail. The analysis of this relationship shows that the smaller the curvature of the rail at the shipment, the greater the axial force. This statement defined the adopted idea of determining the axial forces on the base of the curvature measurement.
- 2 The constructed apparatus to estimate the curvature appeared to be very useful in the

stationary test conditions. The next step in the research of determining axial forces in rails should state the work of preparing the measurement apparatus which would be adjusted to standard machine's work.

- 3 The results of conducted measurements unambiguously indicate on the possibility to collect the valuable information on the lateral resistance during the process of geometrical adjustment. Therefore, further research on this particular topic appears to be totally reasonable. Even with current results, at this stage of the investigation, it is possible to formulate the practical conclusions about the character of the lateral resistance.
- 4 Parallel conducting of any further experiments to determine the values of axial forces in rails and the lateral resistance of the track would get the full effect of cognitive and an optimal use of tamping machine as a diagnostic device.
- 5 Further developing of the numerical model would allow for an investigation of a risk buckling of CWR track, on the base of the experiment's results

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