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Development of condition-based tamping process in railway engineering

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Abstract. Ballast, rails and sleepers form a quasi-elastic track system. When the deformations exceed the elastic limit of the system and the track is no longer lying in its correct position, precautions have to be taken. During a technical track examination several parameters are measured. Should the operational tolerance values of these parameters be exceeded, track maintenance needs to be conducted. Track maintenance includes levelling, lifting, lining and tamping of the track, which is performed by a tamping machine, where the tamping tines penetrate the ballast and compact it beneath the sleeper. For the purpose of this research project, a tamping machine was equipped with a number of strategically positioned sensors in order to perform the in-situ measurements required to describe the interaction of the tamping tines with the ballast and its compaction beneath the sleeper. With a special emphasis on the energy transferred into the ballast and alteration of ballast stiffness during compaction, conclusions concerning efficiency of the tamping process in different ballast conditions are made and presented.

Keywords: Track maintenance; Tamping; Track ballast compaction

1 INTRODUCTION

1.1 Maintenance of ballasted track

Track geometry maintenance was manual labour until 1945 when a mechanical track tamping mechanism, designed by Mr. Scheuchzer in 1933, was put into use. Existing shortcomings of the first design were eliminated by the development of the first hydraulic tamping machine in 1953 by Franz Plasser and Josef Theurer (Esveld 2001). Current practice of track maintenance is entirely based on modern tamping machines that provide a wide range of advance functions such as 4-sleeper-tamping mechanism, dynamic track stabilisation and combined levelling and lining of the tracks.

In the scope of this research project, analysis and improvement of the relevant parameters for compaction of ballast beneath the sleepers are made in order to determine and optimise the factors responsible for the durability of the track geometry after the tamping process.

1.2 Tamping principle

The operating principle of a tamping machine is lifting and lining, i.e. lifting the track up to the level determined by previous measurements and simultaneously position it laterally. Once the track is in the intended position, the tamping tines penetrate the ballast and the tamping process begins (Figure 1). The squeezing movement begins subsequently and is defined as a closing movement of the tines around the sleeper with the objective of refilling the gap created beneath the sleeper and compacting the ballast. The movement is initiated when all tamping tines have reached the desired level above nominal squeezing level. The non-synchronous tamping principle, in which the tamping is performed, described as movement of all tamping tines with the same force, independent of the path, together with directional vibrations, ensures a uniform ballast compaction.

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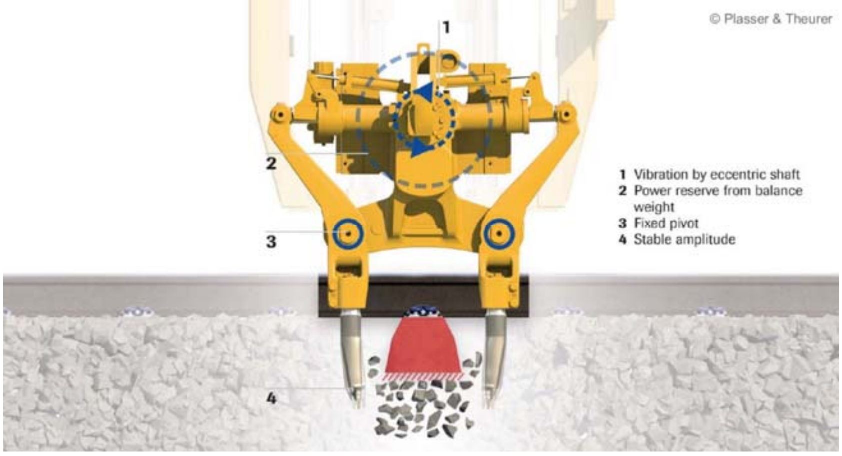

Figure 1. Tamping unit lowered into work position.

2 EXPERIMENTAL APPROACH

2.1 Measuring system

In the scope of this research project tamping machine Dynamic Tamping Express 09-4X E³ was equipped with a number of strategically positioned sensors (Figure 2) in order to perform the in-situ measurements required to describe the interaction of the tamping tine with the ballast and its compaction beneath the sleepers.

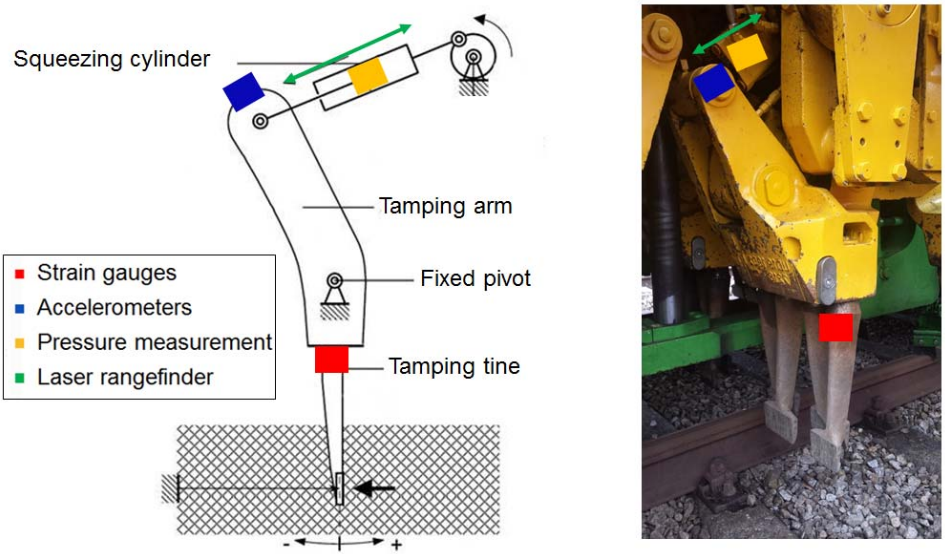

Figure 2. Position of the measuring units.

Strain gauges (see Figure 2, red) are applied on the contact area between the tine and the tamping arm, and are used for measuring both lowering and lateral tamping tine forces. Accelerometers (see Figure 2, blue) placed on the upper point of the tamping arm record the accelerations of the tamping unit in a local coordinate system (axes u and v), and allow a precise calculation of the tine oscillation amplitude. Furthermore, the pressure is measured in the hydraulic cylinders (see Figure 2, yellow), recording its motion, i.e. the beginning and end of the squeezing movement. Cylinder elongation is additionally measured by means of laser rangefinder (see Figure 2, green).

2.2 Tamping process evaluation

Not all components of the squeezing process contribute to ballast compaction beneath the sleepers with the same efficiency. Beneficial to a better and more detailed analysis the process is subdivided into following categories:

- Ballast penetration – lowering the tamping unit
- Squeezing movement – closing movement of the tines around the sleeper
- Lifting the tamping unit
- Tamping unit relocation / Section between two squeezing processes on the same sleeper

Tamping process subdivision allows a determination of energy consumption per category, with a special emphasis on the squeezing movement, contributing mainly to the ballast compaction.

2.3 Load–displacement curve

An initial approach towards successful data analysis implies a newly developed method of dynamic measurement analysis (Plasser Theurer 2017), the load-displacement curve i.e. lateral force-oscillation displacement diagram (Figure 3). This presentation allows an insight into seven parameters essential for a successful data evaluation. During squeezing movement the oscillation amplitude and related lateral force, as well as ballast stiffness during both loading and unloading derived from the curve inclination is recorded. Energy transferred into the ballast calculated as the area within the load-displacement loop is also calculated, and points of tamping tine - ballast contact begin and end are investigated, providing information about the contact duration. During ballast penetration the total inclination of the curve is additionally measured, and allows an insight into the influence of inertial forces on the tamping tines movement and their effect on the consumed energy.

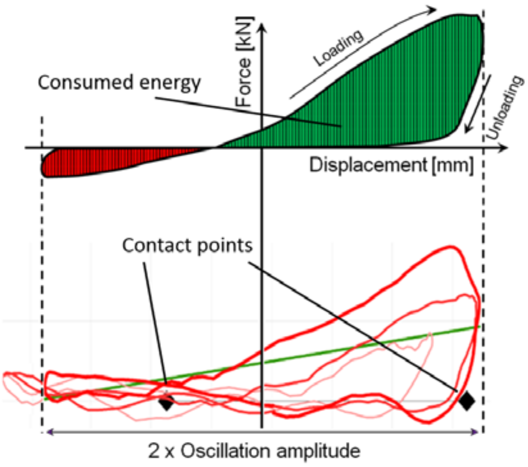

Figure 3. Simplified load-displacement curve per cycle (above), and the curve as a result of the conducted measurements (below).

Depending on the observed part of the tamping process, the load-displacement curve can take several different shapes. During initial contact, while penetrating the ballast, the diagram displays a typical elliptical shape, caused by the unsymmetrical shape of the tine. In the course of a squeezing movement the tamping tines squeeze the ballast beneath the sleeper forming a typical curve, as can be seen in Figure 3. The eccentricity of the curve is attributed to the squeezing velocity, where the negative share of the curve would decrease with the increase of velocity. However, the velocity has to be kept under certain limits for the tamping tine to remain in contact with the ballast for the time required for the energy to be transferred (minimal required impulse duration) (Fischer 1983).

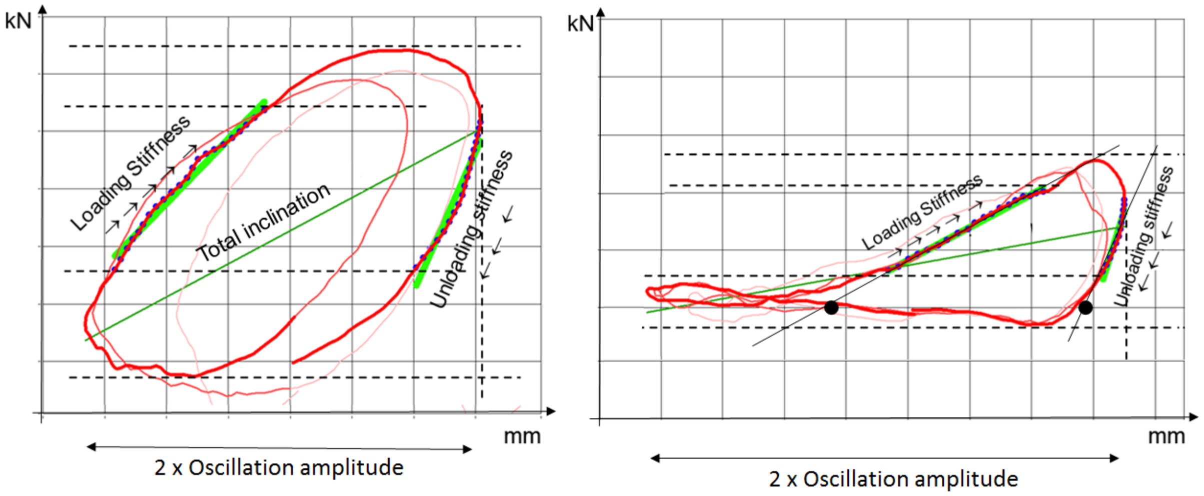

Figure 4. Load-displacement curve during ballast penetration (left) and squeezing movement (right).

It is a theoretical assumption that the ballast stiffness increases with the increase of energy, i.e. with every squeezing of the ballast beneath the same sleeper. The difference between the loading and unloading stiffness describes the plastic deformation of the ballast matrix, i.e. compaction. The plastic deformation of the ballast matrix or its compaction is obtained from the alteration of the loading and unloading stiffness. Third typical display of the load-displacement curve depicts the lifting part of the squeezing process, where tamping tines are simultaneously opened and pulled out of the ballast.

3 EXPERIMENTAL RESULTS

Operation of the Dynamic Tamping Express 09-4X E^3 was monitored at different locations in Austria by means of the measuring system described above, resulting in an extensive series of measurement data. Selected analysis results are presented.

3.1 Graphical data analysis

Depending on its duration every squeezing movement consists of a certain number of cycles. In order to gain a complete insight into every cycle, or to see how the energy of compaction and the ballast stiffness change during the squeezing movement, two graphical data-analysis approaches are selected (Figure 5, example). Showing every single load-displacement curve of a squeezing movement, the progress of ballast compaction as well as a general comparison of two different data sets (i.e. two different ballast conditions) is easily observed. As the ballast compaction progresses the required lateral force as well as the area within the load-displacement loop increases. As a second confident indicator of ballast stiffness, i.e. compaction increase, the enhancement of loop steepness can be noted, indicated by a decrease of distance between the contour lines. Points showing the beginning and end of each tamping tine-ballast contact are depicted overlaying the heat map. In every following cycle the tine reaches the ballast later than in the preceding one, indicating a residual plastic deformation, i.e. ballast compaction.

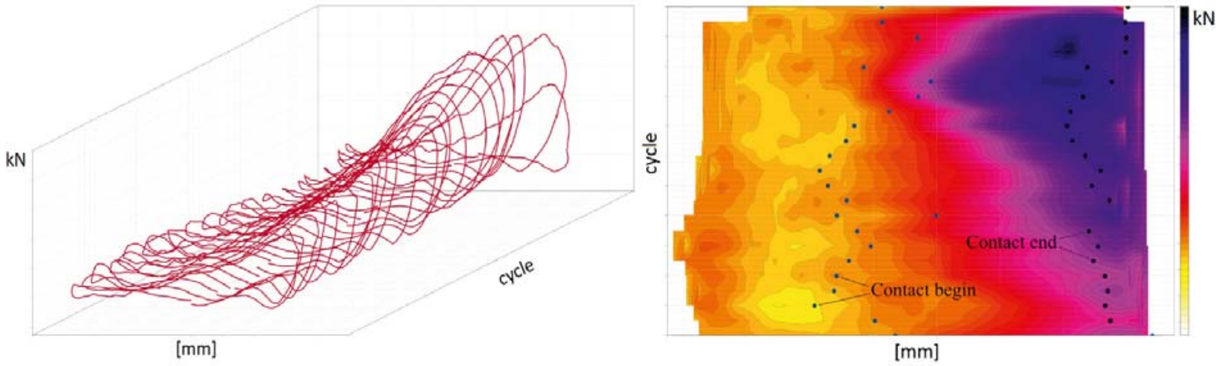

Figure 5. Waterfall diagram (left) and Heat map (right), both showing stacked consecutive load–displacement loops. Heat map additionally depicting points of tamping tine-ballast contact beginning /end.

3.2 Statistical data analysis

However, no reliable conclusions regarding the quality of ballast compaction under the sleeper can be made only through loading stiffness examination. Average values of energy per cycle are necessary, where an increase of energy towards the end of a squeezing movement would further indicate a successful compaction in order to provide a clearer image of the compaction progress. Similarly, a constant stiffness value indicates possible suboptimal squeezing movement duration, where the ballast is not additionally compacted during the process (Figure 6 - the boxes depict the second and third quartile of the analyzed data, whiskers the first and fourth quartile. Black line shows average values per cycle).

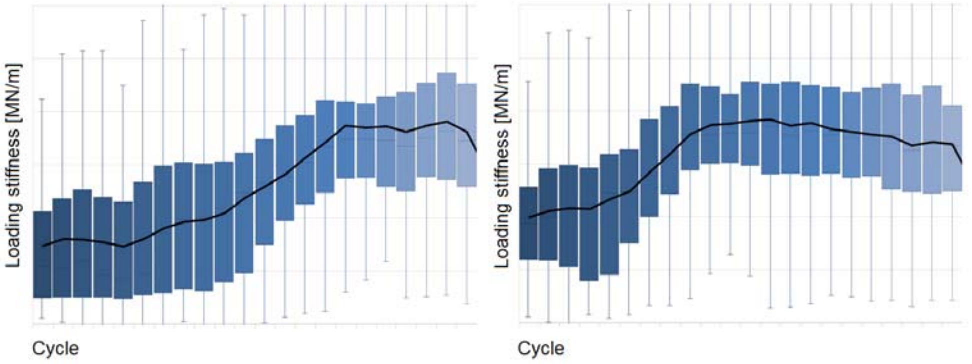

Figure 6. Example of box-plot diagram analysis, showing 400 tamping processes in one location, loading stiffness during the first (left) and the second (right) squeezing movement on the same sleeper.

First statistical analysis is conducted for tamping parameters stated, stating noticeable differences between track maintenance conducted in new and fouled ballast conditions. Significantly higher values of maximal lateral force per cycle are measured during fouled ballast compaction. Taking into consideration that the amplitude of oscillation is kept constant, the lateral force has a direct influence on the total transferred energy during a squeezing movement that doubles in value if comparing fouled and new ballast conditions. Moreover, comparing the ballast stiffness values of two ballast conditions, notably higher values of loading stiffness are measured, as well as negative values of unloading stiffness during new ballast compaction. The differences in the ballast stiffness measured is additionally confirmed by the shape of the load-displacement diagrams for different ballast conditions, showing changes in ballast behaviour and movement during and between cycles. The “negative” stiffness phenomenon can be derived from the tamping tine movement in contact with the ballast during compaction, where the tine continues its motion in the ballast direction after the maximal value of lateral force has been reached, overcoming ballast resistance to compaction. This continuing motion with the decrease of tine velocity indicates new ballast conditions, i.e. soft, clean ballast bedding, with fewer or no fine particles that occur as a consequence of traffic loads and previous tamping operations, thus fouling the ballast bed, and making it more resistant to compaction beneath the sleeper.

4 CONCLUSIONS

The goal of this reaserch project is development of a new, condition-based compaction control and monitoring system for railway engineering. Out of the 7 compaction-control parameters described in detail in (Plasser Theurer 2017), the initial focus lays on the energy transferred into the ballast and alteration of ballast matrix stiffness during compaction, bringing first conclusions concerning efficiency of the tamping process in different ballast conditions. One of the indications of a successful ballast compaction beneath the sleeper is the increase of the ballast stiffness during the squeezing movement. This parameter can also be used as an input for verifying single squeezing movement duration. The most important step towards development of condition-based tamping process is to differentiate between various ballast conditions beforehand and adjust the tamping parameters accordingly. In the scope of this research project a comprehensive study of different ballast conditions, and of finding optimal parameters for compaction is carried out in order to improve ballast serviceability and track life cycle performance.

REFERENCES

Esveld, C. (2001). *Modern railway track*. MRT - Productions

Fischer, J. (1983). Einfluss von Frequenz und Amplitude auf die Stabilisierung von Oberbauschotter (in German), Doctoral thesis. Technical University Graz, Austria.

Indraratna, B., Salim, W. and Rujikiatkamjorn C. (2011). *Advanced Rail Geotechnology – Ballasted Track.* Taylor & Francis Group, London, UK

Plasser Theurer, Export von Bahnbaumaschinen GmbH (2017). Stopfen mit Verdichtungskontrolle - Verfahren und Vorrichtung zum Verdichten eines Gleisschotterbetts (in German), Patent submitted 29.05.2017