University of Pardubice
Faculty of Transport Engineering

METHODOLOGY OF EVALUATION OF THE CONDITION OF FLEXIBLE CLAMPS SKL14 IN OPERATED LINES

Thesis

2020 Ing. Marek Pětioký

Ph.D. student

Ing. Marek Pětioký

Study programme

P3710 Transport Means and Infrastructure

Study specialization

3706V005 Transport infrastructure – structural

Supervisor

doc. Ing. Bohumil Culek, Ph.D.

Supervisor specialist

-

Training department

Department of Transport Structures

Content

1 Introduction

Based on consultations with SŽ, problem sections on the railway network were identified. In general, these can be said sections with arcs of small radii (R <400 m), in which slip waves occur due to operation, the angled guide plates and rail pads wear out and subsequently the individual fastening components are damaged, i.e. clamps, clips, sleeper screws, or even rails - see Fig. 1-1 and Fig. 1-2. Furthermore, a large load seems to be a very important factor. Furthermore, it can be said that sections with all-rubber crossing structures are also problematic. In these places, corrosion of parts of the railway superstructure (clamps, sleepers screws, rails) occurs due to winter maintenance of roads, increased humidity (enclosed space) and possibly the fall of dirt from road vehicles (e.g. sand). To these factors is added the dynamic stress of the fastening components due to road traffic, when the panels of the level crossing structure come into contact with the angled guide plates. The last problem sections that will be mentioned here are railway tunnels. Due to the increased humidity in the tunnels, possibly with the addition of leaks of saline solutions of sanding salts, corrosion damage to the components of the railway superstructure (rails, sleeper screws, clamps) occurs. It is necessary to respond to the above problems from practice and find appropriate measures to identify the causes and eliminate adverse consequences. Therefore, this dissertation was prepared. The work is focused on flexible clamps Skl14, whose function in the railway superstructure is very important for the safety of railway transport.

Fig. 1-1: Clamp with large corrosion loss of material

Fig. 1-2: Cracked clamp

2 Current state of the studied issues

Important documents that deal with this issue include, in particular, Technical Terms of Delivery No. 1 / SŽDC / 07 and General Technical Conditions for Flexible Clamps and Clamps, which set requirements for the basic characteristics of clamps and also set requirements for their testing. Requirements for the properties of the fastening system are further specified in a row of standards ČSN EN 13481 and the methods of testing the fastening system are then specified in a row of standards ČSN EN 13146.

In the bachelor's and master's thesis, a numerical study of flexible fastening with Skl14 clamps was solved at CTU. The problem of these works is insufficient verification of input parameters of models and confrontation of results with real state. Input and output values differ in the bachelor's and master's thesis, in the diploma thesis the values of displacement of the middle nose of the clamp when tightening approximately half were used. For the purposes of this dissertation, it was possible to use a model of the fastening system.

Corrosion of fastenings are mainly dealt with by manufacturers looking for effective methods of protection. These are, for example, Vossloh, Schwihag (surface treatment NiroTec©). Likewise, the manufacturer of flexible clamps, the company Vossloh, has processed FEM and analysis and also carries out testing of clamps. Likewise, the infrastructure manager, the Railway Administration, submits expert opinions on problematic sections of lines (e.g. problems with corrosion of parts of the railway superstructure in the tunnel between Prague - Prague Vyšehrad). However, these surveys are not public. There are also reports prepared by Brno University of Technology, in which the stress on the railway superstructure was measured at speeds of 200 km/h and 230 km/h.

Another factor that can be identified in problem areas is the corrugation of the rails (slip waves). BUT deals with this issue (articles, final theses), or within two UIC projects and one TAČR project.

In this section, special attention will be paid to three specific works that are closely related to the topic of the dissertation.

Ing. Vladimír Tomandl, BUT, Faculty of Civil Engineering, Department of Railway Structures and Structures, 2016, Thesis, Experimental analysis of selected rail fastening systems.

The work is focused on measuring and analysing of dynamic effects (vibration, noise). In conclusion, the work confronts the expected areas of use for fastening systems according to regulation S3 with the findings and suggests possible limitations. No restriction was found for fastening system W14. This work is very well processed, it presents a comprehensive overview of the suitability of the use of individual sets. The submitted dissertation on the work of Ing. Tomandl indirectly follows up, especially in the part dealing with measurements in the track, he uses the findings of Ing. Tomandl. However, the presented work deals with clamps. In combination with the work of Ing. Tomandl could therefore be a very useful tool for the infrastructure manager to decide on the appropriateness of using fastening systems in certain conditions.

KESHAVARZIAN, Hasan, Sodayf AHADI a Saeed MOHAMMADZADEH (2014). Assessment of fracture reliability analysis of crack growth in spring clip type Vossloh SKL14 [42]

The paper deals with fatigue damage of flexible clamps due to traffic loads. The paper seeks to develop a method for reliability analysis of flexible clamps Skl14 based on fracture mechanics using fracture reliability analysis, to assess the development of crack on the clamp based on Paris law. The finite element method is also used. The introduction of the article is a detailed research activity in the field. The clamp used on the Iranian railways (scanned by a 3D scanner) was modelled. Using the finite element method, the state is simulated when tightening and passing a railway vehicle. Both states are based on displacements of parts of the clamp over time. According to the experiment, the displacement at a load of about 10.5 mm on the nose of the clamp is under load from the propeller. When loaded by the train, the crack initiation was shown to be close to the maximum value of 1250 MPa at ΔKI, so the Mode I mechanism is dominant for fatigue crack growth. Therefore, if a crack is observed, the clamp should be replaced.

The displacement under load is different in the paper from the measurements, which were performed by the author of the work and was used as an input to the FEM calculation.

FERRENO, Diego, José Antonio CASADO, Isidro Alfonso CARRASCAL, Soraya DIEGO, Estela RUIZ, María SAIZ, José Adolfo SAINZ-AJA a Ana Sabel CIMENTADA (2019) Experimental and finite element fatigue assessment of the spring clip of the SKL-1 railway fastening system [43]

The paper combines an experimental approach and a finite element method. The subject is the assessment of the structural integrity of flexible clamps Skl-

1. The research activity concerning the damage of the clamps is introduced at the beginning. The conclusion of most authors is that the clamps are damaged by fatigue.

Samples of 38Si7 steel were prepared and unheated and heat-treated samples were subjected to testing similarly to the production of clamps. Furthermore, the clamps were tested directly. The following measurements were performed. Hardness on the clamp and samples - about 400 - 450 HV. Tensile test on unheated and heat-treated specimens - yield strength 1291 MPa, yield strength 1077 MPa. Fatigue test - at $\sigma_m = 0$ $\sigma_e = 301$ MPa was found, at $\sigma_m \neq 0$ $\sigma_e = 291$ MPa was found. The N_f was then found to be about 490,000 cycles. Fatigue life depends not only on the amplitude but also on the mean value of the stress. According to the authors, the linear combination of Goodman's and Gerber's correction describes the behaviour of the 38Si7 clamp material very well.

Experimental results on clamps. A quasi-static test was performed. Up to 8 kN, the clamp reacted elastically, then plastic behaviour occurred. When moving approx. 15 mm, the middle nose of the clamp came into contact with the rail. After unloading, plastic deformations remained, proving that the elastic limit was exceeded. The von Mises stress at a load of 25 kN (tightened clamp, force floated by lifting the outer arms of the clamps - simulation of lifting from the rail) was found to be about 1300 MPa, which exceeds the yield strength. Furthermore, a fatigue test was performed ($F_m = 2.5$ kN, amplitude $F_a = (F_{max} - F_{min}) / 2$, between 2 and 1.2 kN, 3 million cycles, 12 samples). The fatigue limit F_e was found to be 1200 MPa (depending on the mean value of the load, in this case 2500 N). Furthermore, the load conditions were reproduced as in the operated track (3 million cycles, frequency 5 Hz, minimum load 5 kN and maximum load 70 kN, arc simulation). Twelve samples were tested, all of which lasted for 3 million cycles without failure. The results of the numerical analysis show that the maximum adjusted clamp amplitude reaches σ_a (σ_m = 0) = 134 MPa, while the fatigue limit reaches σ_e = 301 MPa.

According to the authors, damage due to fatigue is a very unlikely event, which is, however, cited as the cause of damage by other authors and also by the author of this work.

2.1 Summary of current state

The field of dissertation is the subject of interest in other research, but the specific focus is different and the work therefore brings new knowledge to the problem.

3 Objectives of the dissertation

- The main goal of the work is to create and verify the methodology for evaluating the condition of Skl14 clamps in the operated lines, the methodology defines various evaluation criteria and determines the method of their verification.
- Identification of line sections with a higher degree of damage to flexible clamps in the operated railway network, analysis of causes.
- Verification of the properties of the Skl14 clamps.
- Comparison of corrosion resistance of Skl14 clamps without anti-corrosion surface treatment and with anti-corrosion surface treatment KTL.
- FEM analysis of the clamp voltage Skl14.

4 Verification of clamp properties

The work is divided into 3 basic parts, namely the verification of the properties of flexible clamps, the design of the methodology and its verification.

I verified the above properties especially at the workplaces of the Education and Research Center in Transport (VVCD), Section of Materials Engineering under the leadership of prof. Schmidová, Dynamic and Test State Section under the leadership of doc. Culek and at the workplace of the Institute of Chemistry and Technology of Macromolecular Substances, Department of Paints and Organic Coatings under the leadership of prof. Kalendová.

4.1 Tensile test

4.1.1 Sample preparation

To verify the mechanical properties of flexible clamps, especially to determine the value of limit of strength and yield strength, a tensile test was performed. Test specimens were made from the clamps - see Fig. 4-1

Fig. 4-1: Sample for tensile test

The measuring device was Zwick Z030. A test specimen was clamped in the jaws and a loading cycle was started with a step of 0.002 s^{-1}, which was controlled and recorded by a PC, specifically with the Zwick testXpert Master program. The results were exported in the format of path in mm and force in kN and subsequently evaluated in Microsoft Excel - see Fig. 4-2.

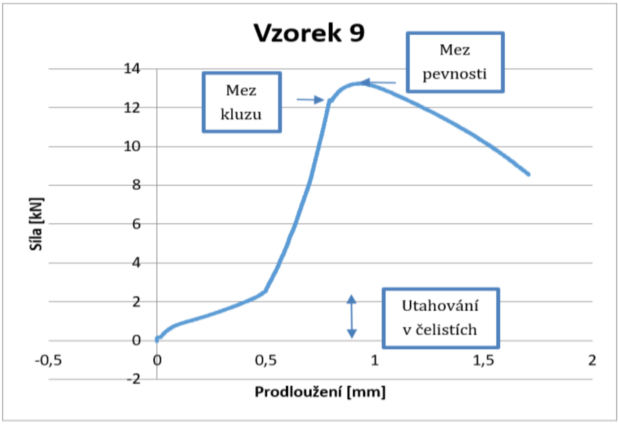

Fig. 4-2: Record from tensile test

Yield strength values were found in the range of 1289 to 1376 MPa, limit of strength values in the range of 1392 to 1492 MPa. If the determined values are compared with the values according to ČSN EN 10089, which are given for the steel from which the clamp is made (38Si7), i.e. the yield strength of 1150 MPa and the limit of strength between 1300 and 1600 MPa, it is clear that the limit values yield strengths are above the values specified in the standard, the values of the limit of strength are then within the limits specified by the standard.

4.2 Fatigue

Fatigue tests were performed on material samples removed from the clamps - see Fig. 4-3. The measuring device was an INOVA electrohydraulic system using the AH100-40 cylinder. A test specimen was clamped in the jaws and harmonic loading was triggered - see Fig. 4-4.

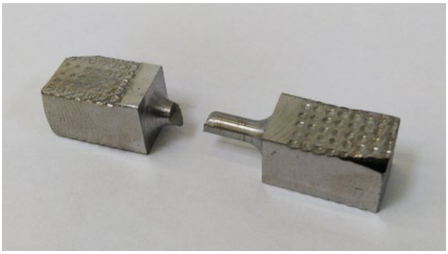

Fig. 4-3: Sample after fatigue test

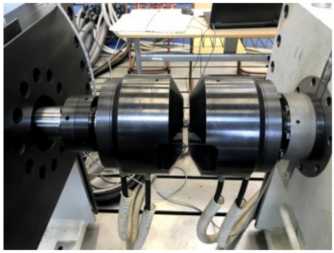

Fig. 4-4: Clamped specimen during fatigue test

The mean value of the oscillation was chosen to be 4 kN due to the stability of the system. The loading frequency was 10 Hz. The resulting relevant values of the number of cycles to fracture were tabulated and a fatigue curve was constructed, which were subsequently transformed to a zero mean value according to Goodman. The characteristic values of the fatigue curve were found to be m = 23.181 and log c = 75.765 - see Fig. 4-5. The contractual fatigue limit at zero mean value determined by the Smith chart was 997.56 MPa.

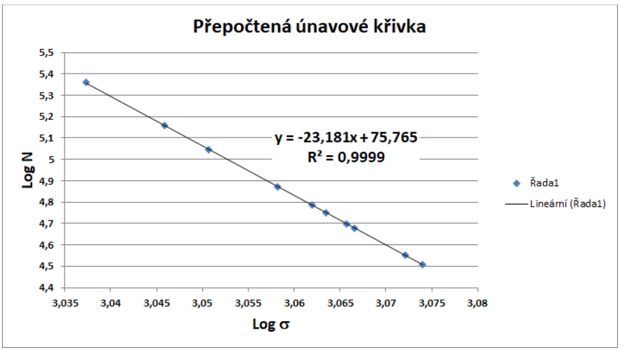

Fig. 4-5: Fatigue curve

4.3 Metallography of flexible clamp Skl14

Verification of the properties of flexible clamps, which are defined in [1], was performed by metallographic analysis of flexible clamps. A light microscope and an electron microscope were used in this analysis, and the hardness of the flexible clamps was also verified by the Vickers method.

A new Skl14 clamp without anti-corrosion surface treatment was used for metallographic analysis. A part of the arm was cut from the clamp (with a MTH MIKRON 110 saw), including a flattened place. In order not to thermally affect the sample, the sample was cooled during cutting. After cutting, the sample was pressed into bauxite (BUEHLER SimpliMet 3000 press), followed by grinding the sample on sandpaper of various roughnesses and polishing the sample with diamond paste. To highlight the structure of the sample, the surface was etched with 3% Nital (a solution of nitric acid in ethyl alcohol).

4.3.1 Examination with a light microscope

A NEOPHOT 32 light microscope was used for the examination. First, the sample was examined in an unetched state. In the unetched state when enlarged according to the related standards, a possible increased occurrence of impurities in the surface layer, or occurrence of surface microscopic defects. In both cases, no significant indications were found in relation to the load-bearing capacity of the clamp. Therefore, the sample was etched with 3% Nital, as mentioned above. After etching the sample, uneven decarburization was found on the sample surface. According to [4], in the case of finished products, the decarburised layer must not exceed a thickness of 0,2 mm, which was observed for the given sample. Furthermore, heterogeneity was found in the core of the sample. Heterogeneity in the sample core indicates that the sample was not hardened in the entire cross section. When examining the surface of the sample, incipient corrosion was also found.

4.3.2 Examination by electron microscopy

The sample was gilded before being placed in the electron microscope. The reason is to ensure conductivity so that it does not charge electrons when its surface attacks. A TESCAN 5130SB electron microscope and SW Analysis were used. The examination confirmed the findings from a light microscope, i.e. decarburization of the sample surface to ferrite. Decarburization to ferrite can result in reduced corrosion resistance, which has also been confirmed and corrosion of this decarburized zone has been found. Decarburization of the surface layer also has a negative effect, especially on fatigue resistance. Furthermore, the presence of microscopic inclusions was detected. After analysis of these inclusions, it was found that it is mainly the presence of complex oxides, i.e. Al2O3 with the presence of other elements according to the affinity for oxygen. Another finding was the finding of a small amount of carbides in the surface of the sample, indicating a low tempered material. The surface structure of the sample was martensitic. After evaluation of the sample with a light and electron microscope, it can be stated that no deviations from the values declared by the manufacturer in [1] were found.

4.3.3 Vickers hardness test

A Zwick / Roell ZHU 2.5 hardness tester was used for the measurement. The sample was cut and ground. It was measured by the Vickers method according to ČSN EN ISO 6507-2. A tip with a force of 300 N was pushed into the material, followed by unloading and measuring the area created by the impression. The whole process was controlled automatically by a computer with special SW. The measurement was performed from the core of the sample to its edge by about 1.5 mm. From the measured values it is clear that the values are in the range of 434 - 455 HV30. The manufacturer declares the hardness of the flexible clamps Skl14 to 400 - 460 HV30 [1], the requirements are within these limits.

4.3.4 Evaluation of the metallography of the flexible clamp

At the end of this chapter it can be stated that the flexible clamp Skl14, which has been subjected to metallographic examination, meets the requirements

[1], in all examined parameters. Effects reducing corrosion and fatigue resistance were found, but to the extent permitted for the product.

4.4 Simulation of corrosion on samples in the laboratory

In order to determine how resistant, the Skl14 flexible clamps are to corrosion, they were tested in a simulated corrosive environment in the laboratory. Two tests were performed, first a test with neutral salt spray according to ČSN EN ISO 9227, then, to induce greater corrosion damage, an immersion test in an electrolyte solution. Clamps without anti-corrosion surface treatment and with anti-corrosion surface treatment KTL were compared.

4.4.1 Neutral salt spray test according to ČSN EN ISO 9227

40 samples were subjected to the neutral salt mist test, of which 20 samples were without anti-corrosion surface treatment and 20 samples with KTL surface treatment. The samples were placed in a corrosion chamber where they were exposed to 5% NaCl at a temperature of 35±1 °C. The test was performed in twelve-hour cycles. In these cycles, the samples were exposed to 5% NaCl mist for six hours, followed by drying the samples at 28 °C for two hours, and the cycle was terminated by condensing moisture at 40 °C for four hours. The corrosion chamber SKB 400 A-TR manufactured by Gebr. Liebish GmgHCo, Bielefeld, Germany, chamber type number is 41066211. The corrosion chamber recorded a total test time of 1720 h. During the test, the samples were monitored and the sample was photographed continuously. After 1720 h, it was decided to end the testing in the corrosion chamber. During the inspection of the tested samples in two consecutive periods, there was no significant increase in the layer of corrosion products. The biggest cause for samples without anti-corrosion treatment was the formation of a barrier from corrosion products on the surface of the tested samples. These corrosion products partially prevented the penetration of the corrosive

environment to the clamp material. Unfortunately, it was not possible to laboratory simulate a combination of a corrosive environment with repeated dynamic loading. Clamps with a KTL coating did not show too much corrosion. Only local manifestations of corrosion appeared.

4.4.2 Immersion test in electrolyte solution

The samples were immersed in a solution of an electrolyte consisting of 5% NaCl and 3.5% (NH 4) 2 SO 4 in distilled water. The electrolyte solution was aerated with compressed air every 48 hours for about 5 minutes. After about 30 days, the samples were removed, immersed for about 5 minutes. into the pickling solution and subsequently the residual corrosion products were mechanically removed and the residues of the pickling solution were removed from the samples by a stream of distilled water. The pickling solution was prepared by dissolving 5 g of urotropin (hexamethylenetetraamine) in 1 l of 20% HCl. [2, 3] The pickling solution was used to remove corrosion products from the surface of the flexible clamps. By removing the corrosion products, their barrier effect was removed and the corrosive environment could more effectively attack the surface of the flexible clamps. After treatment, the samples were placed in a newly prepared electrolyte solution. The old electrolyte solution was removed as it contained a large amount of corrosion products. Half of the samples were used for the test, which were removed after the 1720 h test with neutral salt spray, i.e. 10 samples without anti-corrosion surface treatment and 10 samples with KTL surface treatment. In total, the samples were subjected to 3 cycles of immersion test for a total of 96 days, about 2300 h. clamp without anti-corrosion coating 459.20 g as with KTL coating 494.71 g 66 %, i.e. about 11 times more.

4.5 Clamping force tests

The measurement was performed using a special device borrowed by Vossloh and a standardized test according to ČSN EN 13146-7.

4.5.1 Measurement of the clamping force with a Vossloh device

A jaw is mounted on the outer arms of the clamp, which ensures that these arms are pulled upwards. The clamp is tightened to the prescribed torque, 200 Nm was applied for measurement purposes. Subsequently, a frame is placed on the sleeper, on which the load cell is attached. By tightening the screw, the outer arms of the clamp are lifted and at the moment when it is possible to insert a 0.1 mm flat gauge under the clamp arm, the value on the load cell is read. See Fig. 4-6.

Fig. 4-6: Vossloh device for measuring of the clamping force

A value is read and recorded for each outer arm, i.e. two values are recorded for one clamp. Subsequently, the values are averaged and the resulting average is multiplied by a factor of 0.88. This coefficient is determined by the manufacturer of the test equipment, it serves to compensate for the different geometry of the test equipment (different lever arms). 10 new clamps were measured, the values of the clamping force were found in the range of 9.68 - 10.89 kN, which corresponds to [1] and [9].

4.5.2 Measurement of clamping force according to standard ČSN EN 13146-7

The new clamps were also measured according to the standardized procedure according to the ČSN EN 13146-7 standard. The procedure measures the fastening node, i.e. 2 new clamps. The clamps were tightened with a tightening torque of 200 Nm. The value of the clamping force was found to be 17.78 kN, which does not meet the requirements [9], the requirements [1] were met.

4.5.3 Comparison of measurement procedures

The resulting values obtained with Vossloh device show higher values than the values determined by the standardized procedure. The difference can be explained by a different approach to measurement, i.e. the measurement of the whole node in comparison with the measurement of only one clamp. It should also be taken into account that the measurement with Vossloh device does not show such accurate measurement values, the results were read at 0.25 kN. For the purposes of the work, it is more advantageous to measure only one clamp, not the whole fastening node, therefore the measurement will use the Vossloh device in the work.

4.5.4 Dependence of the clamping force on the diameter of the wire thickness of the clamps and the weight of the flexible clamps

By Vossloh device 10 clamps were measured with different levels of corrosion. For these clamps, the diameters of the clamp wire were measured at 4 locations - see Fig. 4-7 and the weight of the clamp was measured. According to [9], the required value of the clamping force is min. 8 kN (measurement according to the standardized procedure according to ČSN EN 13146-7). Due to the difference in procedures and measurement method, a tolerance of ± 0.5 kN was considered. From the measured values of clamping forces and corresponding measurements of wire diameters and clamp weights, it can be deduced that if the wire diameter at any measured point 1 to 4 is less than 12 mm and the clamp weight is less than 470 g, then the clamping force value does not meet the requirements [9] taking into account the tolerance considered. The wire diameter of the new clamp is 13 mm, the weight of the new clamp is approx. 492 g.

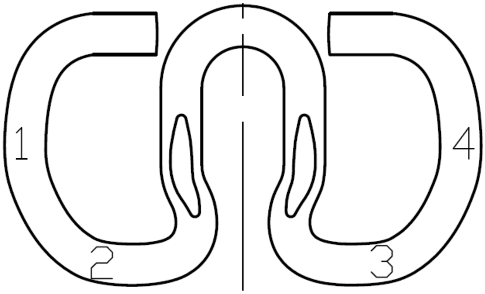

Fig. 4-7: Marking of places for measuring the wire diameter of flexible clamps

5 Modelling of fastening system W14 by finite element method

SolidWorks 2014 software was used to create the FEM model and calculations. Nonlinear analysis was used for the calculation, the solver was Large Problem Direct Sparse. The standard components of the W14 fastening system were used for the model, which are used on B91S sleepers and are approved for use on lines in the Czech Republic. The sleeper was not used in the model, it was replaced by a fixed geometry. The replacement of the sleeper and the simplification of the geometry by means of symmetries was used due to the reduction of the computing power of the PC and a negligible influence on the calculation results. The sleeper screw was not used, the clamp load (simulation of tightening with the prescribed torque) was introduced using the reference geometry. The behaviour of the clamps was modelled only when tightened to the prescribed torque under different compressions of the clamps given by different reference geometries (12.6 mm to 13.4 mm by 0.2 mm). Sections were made at the locations of the strain gauges (see 7.2.2) and changes in stress along the cross section of the clamp were found - see Fig. 5-1.

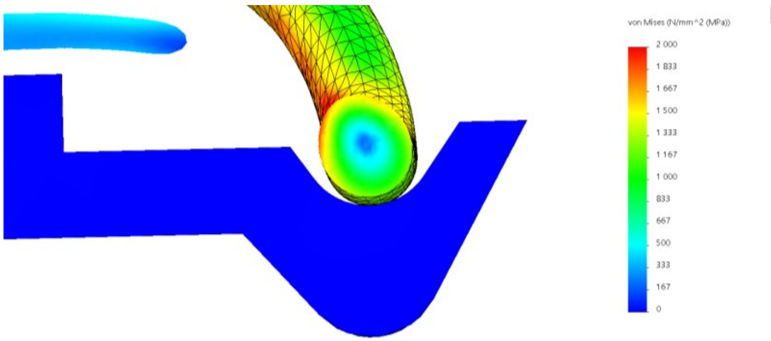

Fig. 5-1: von Mises stress in section at point 2

Higher values are achieved when tightening the clamp in place at the angular guide insert. It is clear from the obtained values that von Mises stress values of up to 1900 MPa were achieved during tightening, the stress values gradually decrease towards the center of the clamp, where values of approx. 100 to 200 MPa are achieved. The clamp will not be damaged during tightening with the prescribed tightening torque, even if the strength limit is locally exceeded (according to [4] it is 1300 MPa to 1600 MPa, verified by tensile test). High stress in the surface layer reduces the corrosion or fatigue resistance of the clamp. The results are summarized in Tab. 5-1.

Tab. 5-1: Von Mises stress at different tightening values

	Řez	Napětí von Mises při zdvihu [MPa]				
		12,6 mm	12,8 mm	13 mm	13,2 mm	13,4 mm
Minima	Osa y_řez 1	108	103	140	135	102
	Osa z_řez 1	99	120	136	143	120
	Osa x_řez 2	176	186	146	173	183
	Osa y_řez 2	179	227	191	212	185
Maxima	Osa y_řez 1	1257	1238	1297	1326	1310
	Osa z_řez 1	902	906	926	932	950
	Osa x_řez 2	1755	1835	1811	1823	1902
	Osa y_řez 2	1514	1530	1569	1584	1614

Furthermore, the combined load given by the transverse and vertical movement of the outer arms of the clamps was modelled. A transverse load of 5 mm and a vertical load of 1 mm were applied. The values of the transverse displacement are larger than the values measured in the Kolín railway station, but the detected behaviour of the model, resp. the places of the highest stresses coincide with the places where the flexible clamps are damaged in the Kolín railway station, i.e. in the middle of the outer arm of the flexible clamp. From the application of transverse displacements of different loads, it can be said that the larger the magnitude of the transverse load, the more the value of the maximum stress shifts from the angular guide insert to the center of the outer arm of the flexible clamp. High values of stresses were found on the surface of the clamp, which gradually decrease towards the center of the clamp. The value of von Mises stress of 293 MPa was found in the middle of the clamp, while the value of this stress of 1936 MPa was found at the edge of the cross section. Roughly midway between these values, von Mises has a stress of 908 MPa.

6 Methodology for evaluating the condition of flexible clamps Skl14 in operated lines

Although the use of products in operated SŽ lines is subject to prior certification, which includes the requirement to meet the General Technical Conditions (OTP) and technical conditions of delivery (TPD) and subsequent operational verification, SKL14 clamps cannot avoid failures arising during operation in difficult situations (curves with small radii, railway crossings, lines in tunnels). Identification of the degree of damage and subsequent evaluation of further use of SKL 14 clamps is addressed in the draft Methodology for evaluating the condition of flexible clamps SKL14 in the operated lines.

6.1 Proposal of methodology

The methodology for evaluating the condition of SKL14 flexible clamps in operated lines is focused on the key issue of failures. Due to the fact that failures are caused by various factors (geometry, structure, static prestress, dynamic load, corrosion), the methodology is divided according to the following factors:

1) **Evaluation of the response to static prestress**
   - After tightening the clamp (its compression / stroke) to the prescribed torque by the pressing force, this will cause internal stress in the clamp. There is a direct dependence between this stress and the clamping force, the quantities can be evaluated separately and the remaining ones can be calculated using FEM.
   - **Stroke evaluation** - theoretical stroke value 13 mm (exceeding, not reaching), static preload of the clamp after tightening.
   - **Stress evaluation** - FEM model (characteristic value of stress in critical places of clamps), surface tension can be measured using tensometric measurement.

- **Evaluation of clamping force -** measurement according to ČSN EN 13146-7 or Vossloh, comparison of measured values with TPD, OTP.

2) **Evaluation of clamp fracture**
   - **Fractographic analysis -** identification of the failure mode, crack initiation sites.

3) **Corrosion evaluation**
   - Direct effect on the size of the clamping force, significant effect on the dynamic behaviour (reduces the fatigue strength of the clamp).
   - **Evaluation of the percentage weight loss -** the evaluation criterion is the limit weight loss due to corrosion, when the clamping force drops below 8 kN on the clamp, taking into account the tolerance of ± 0.5 kN. Based on the experiment, the value of the limit weight of the clamp due to corrosion was found to be 470 g.
   - **Evaluation of the remaining wire diameter -** based on the performed experiment, a diameter loss of 1 mm is permissible. With a diameter of less than 12 mm, the clamping force drops below 8 kN, taking into account a tolerance of ± 0.5 kN.

4) **Evaluation of the response to dynamic loading**
   - Significant influence on the fatigue life of the clamp. If fatigue damage is detected by fractographic analysis, then a fatigue assessment based on the stress spectrum corresponding to the representative load and the fatigue curve must be performed. A representative spectrum can be obtained using:
     - measurement of vertical and transverse rail displacements and subsequent use of FEM for stress determination,

  - measurement of the vertical wheel and transverse guide force acting on the rail and the subsequent use of the FEM to determine the stress.
- **Identification of surface tension on the clamp from operation** - tensometric measurement on the arms of the clamp by means of strain gauges. The comparison / support criterion is the equivalent stress (HMH / Von Mises).
- **Identification of vertical wheel and transverse guiding forces** - tensometric measurement of rail web deformation. Additional measurements.
- **Identification of vertical and transverse displacements** - based on the identification / measurement of rail foot displacements and FEM conversion tables, a modified stress record on the clamp can be generated. The evaluation criterion is the fatigue limit in the vertical (± 1 mm) and transverse (+ 0.6 / - 0.2 mm) direction.
- **Evaluation of fatigue damage** - based on real stress records found directly in the track. The basis for evaluation is:
  - an adjusted representative time record of the clamp stress determined at the critical point (the time record is modified to express the equivalent / reduced stress according to the HMH hypothesis) including static preload,
  - defined fatigue curve,
  - defined clamping load history.

  The evaluation is based on the Palmgren-Miner hypothesis of fatigue damage accumulation. The result is a specific value of fatigue life (can be compared with the real life of clamps in real lines).

5) Acceleration evaluation

- Evaluation of the effective value of acceleration (RMS).

  - Measurement of the acceleration of the rail foot in the vertical direction is decisive for determining the comparative energy parameters RMS (effective value of acceleration) and identification of the frequency causing the so-called waviness.
  - It is possible to identify local maxima and minima of acceleration and thus the possible damaging effect of individual axles on the mounting.
- **Evaluation of slip waves** - determination of the frequency value of the occurrence of waviness under operating load in the context of individual passages of load sets can be an additional data to the overall evaluation of clamps Skl14.

Due to the proposed criteria (geometric, material), these criteria must be understood comprehensively, not separately, e.g. corrosion loss affects the stiffness of the clamp (reduction of prestressing force, reduction of fatigue strength, etc.).

The choice of assessment method should always correspond to the symptoms accompanying the fixation defects. Symptoms can be characterized as obvious defects, such as fractures of the clamp arms, excessive corrosion loss, GPK defect, slip waves, pressure of the clamp in the rail or angle insert, etc.

7 Verification of methodology

The measuring point is located in a curve with a radius of 190 m with an elevation of 56 mm and a speed of 50 km/h located on the line 502A Kolín – Nymburk – see Fig. 7-1 and Fig. 7-2. The location was chosen due to the faults that occur in the location (slip waves, cracking of the clamps, etc.).

Fig. 7-1: Place of measurement in Kolín railway station

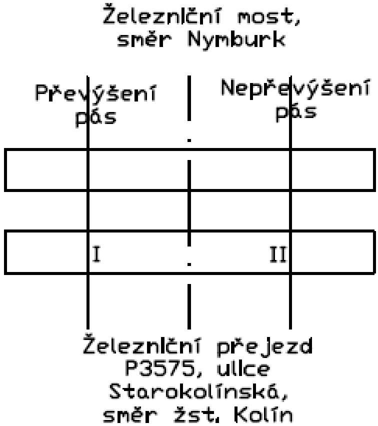

Fig. 7-2: Track markings

7.1 Fractography of the clamp from the Kolín railway station

The fracture surface of the clamp from the crossing in Kolín, which did not completely break the outer arm, was examined by electron microscopy. The aim of this investigation was to find out which fracture caused the clamp to fail. It was found that the sample was fatigue damaged with multiple sites of initiation - see Fig. 7-3 and Fig. 7-4. This finding is very important for finding possible causes of why a given quarry occurs. The fracture occurred despite the fact that the clamp was not loaded for a long time (the clamps were in operation for 3 years) and there was no noticeable large corrosion loss.

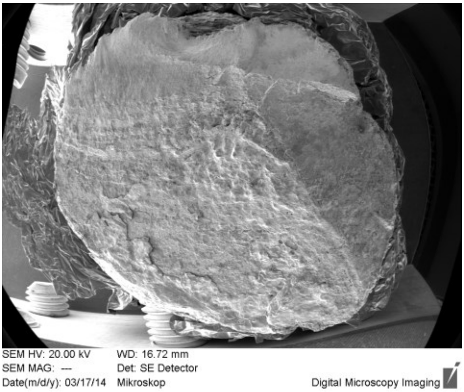

Fig. 7-3: Sample for fractography

Fig. 7-4: Sample for fractography - findings

7.2 Evaluation of the response to static preload

7.2.1 Stroke evaluation

The clamps were tightened to 200 Nm and further to 220 Nm. The sleeper screw was tightened so that it came into contact with the clamp, which is taken as the initial state. A metal plate was glued to the sleeper and a magnetic stand was attached to it, into which an inductive displacement measurement sensor was clamped. The tip of the sensor was placed on the middle nose of the clamp, to which the propeller was tightened. Subsequently, tightening to the prescribed torque took place. The sensors were connected to the measuring amplifier HBM DMC Plus, where the analog recording was digitized at the same time. Digitized shift records were registered to a PC via the HBM Catman software.

At values of tightening torques of 200 Nm, stroke values of 13.4 mm and 13.5 mm were measured. At tightening torque values of 220 Nm, stroke values of 13.5 - 13.7 mm were measured.

7.2.2 Stress evaluation

Measuring clamps (in the number of 2 pieces) were fitted with strain gauges in two different positions (a total of 4 pieces of roses). The positions of the sensors were chosen with regard to the places of greatest stress according to the FEM calculation of the manufacturer, the company Vossloh and with regard to the statistical evaluation of damaged clamps after 3 years of operation - Fig. 7-5 and Fig. 7-6.

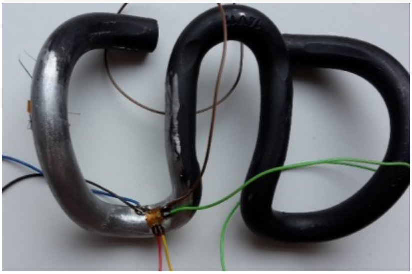

Fig. 7-5: Strain gauge location - place II

Fig. 7-6: Strain gauge location - place I

The strain gauges 1-RY11-3 / 120, 0 ° / 45 ° / 90 ° with grids with a length of 0.8 mm, a nominal resistance of 120 Ohms and a k-factor of 1.85 were chosen for the measurements. The connection was made to a half-bridge Wheatstone bridge (temperature compensation was also placed directly on the clamp). El. connection of the measured points was analogous in all places of both measuring clamps. The strain gauges were connected to the measuring amplifier HBM DMC Plus (where the analog recording of deformations / stresses was also digitized). Digitized stress records were registered to a PC via the HBM Catman SW. The gain was set in the measuring control panel according to the strain gauge constant, the maximum power supply and the type of connection. The sampling frequency for the measurement was 600 Hz. The resulting measured values of deformations on individual rosette strain gauges were subsequently used to determine the principal and reduced stresses at the measurement points using Hooke's law for plane stress. The measuring clamps were tightened with a torque wrench to a value of 200 Nm. The clamps were placed on the inside of the rails. The measuring point was located in the right track in the direction of the railway bridge, track no. 114. Clamp marked II (inner clamp for canted rail, there should be more stress in case of excess cant), clamp marked I (inner clamp for canted rail, there should be more stress in case of cant deficiency). Clamp locations were selected based on observations of damaged clamps.

The stresses on the clamps were measured during tightening, when the clamp was gradually tightened to 50, 100, 150, 180, 200, 220 Nm and then completely loosened, resp. allowed to a value of 200 Nm. Tightening was performed with a calibrated torque wrench with an alarm clock. An example of a record is shown in Fig. 7-7. The determined values of reduced stresses are given in Tab. 7-1.

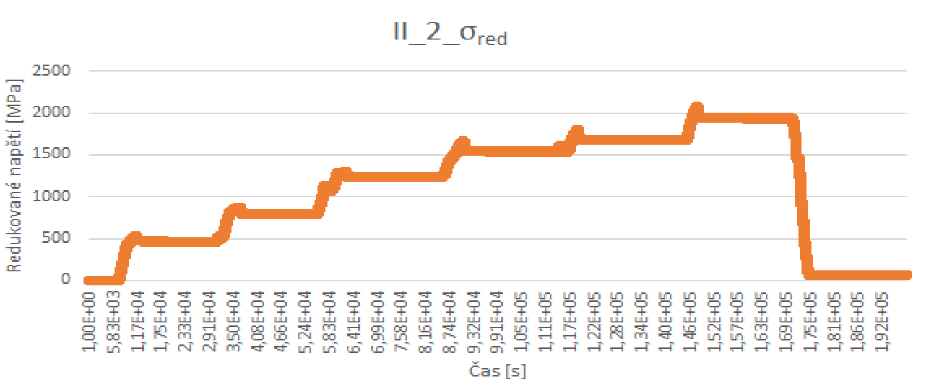

Fig. 7-7: Record of flexible clamp tightening measurements

Tab. 7-1: Reduced stress values found during tightening

	Svěrka_II_1	Svěrka_II_2	Svěrka_I_1	Svěrka_I_2
	σ_{red}	σ_{red}	σ_{red}	σ_{red}
	[MPa]	[MPa]	[MPa]	[MPa]
Měření 01	887,014	2068,590	x	x
Měření 02	899,254	2137,032	x	x
Měření 03	x	x	974,635	1977,293
Měření 04	x	x	961,121	1794,913

7.2.3 Evaluation of clamping force

Implemented by Vossloh device - see Fig. 4-6 - on clamps with different degrees of corrosion attack. The degree of corrosion attack was given by the remaining wire thickness after corrosion cleaning (mechanical cleaning). For reasons of comparability / comparison, clamps from other line sections were also included in the measurement. Values confronted with the experimentally found - wire diameter min. 12 mm and clamp weight min. 470 g (clamping forces min. 8 kN taking into account a tolerance of ± 0.5 kN). The results are as follows: Žst. Kolín - 21 samples, passed 3; Dobříň - 31 samples, passed 4. The criterion determined by the methodology was confirmed, the diameters of the wires, the weights and the clamping forces corresponded to the criteria. Poříčany - 8 clamps, 2 failed; TÚ Český Brod - Poříčany - 8 clamps, 5 failed. The influence on the clamping force was not dominated by corrosion loss of the material of flexible clamps (clamps without significant corrosion loss), but the effect of repeated loading, the clamps were removed from a heavily loaded track by railway traffic, where they were stressed for 15 years.

From the point of view of the influence of corrosion loss on the magnitude of the clamping force, the following recommendations can be deduced:

- Carry out regular inspections of the railway superstructure, during which a visual inspection of the clamps will also be carried out with regard to the corrosive loss of material. If a wire thickness of less than 12 mm and a weight of less than 470 g are detected, the clamps must be replaced. If clamps without anti-corrosion surface treatment have been used, or with an already unpromising or possibly unused one (e.g. KTL), insert clamps with the current best possible anti-corrosion treatment.

- To check for any negative manifestations on the GPK measurement records, if higher values are manifested, especially in the track gauge, it is necessary to analyse the section as in the case described above. Not all places are accessible for visual inspection, e.g. crossings, so it is necessary to deal with these sections of lines, which will allow the outputs of GPK measurements.

7.3 Evaluation of the response to dynamic loading

7.3.1 Identification of surface stresses on the clamp from operation

Measured vehicles of series 122, 123, 854, 162, 471, 130, 163, 730, 740, 386, pušl, tamping machine + cars; speeds 27 - 52 km/h; 23 records. The measuring clamps used for measuring the stresses during tightening are used - see 7.2.2. Tightened clamps were taken as a starting point for measuring the stresses from passing vehicles. It is therefore necessary to take into account the stress caused by tightening the clamps to the specified torque.

An example of a record is shown in Fig. 7-8.

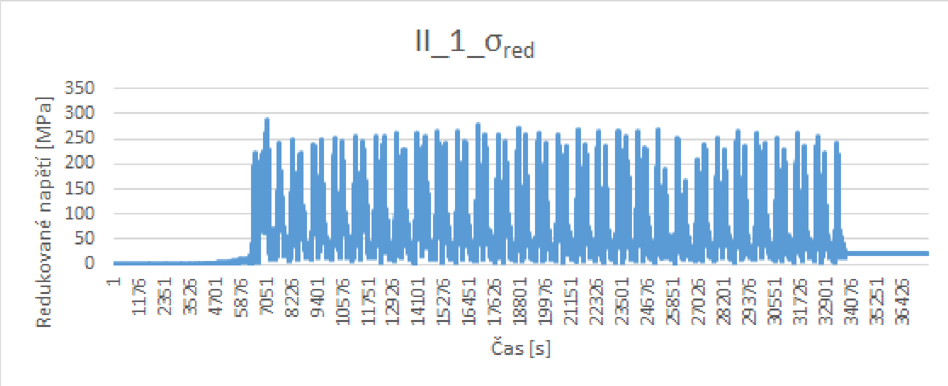

Fig. 7-8: Recording of reduced stresses during the passage of the vehicle

Higher values of equivalent stresses were achieved on the outer arms of the flexible clamps (vertical and transverse movement of the clamp arms). The maximum value found is 288.43 MPa (record 12_46_122027_28 of the car). The maximum value of the equivalent stress of 159.92 MPa was found in the middle part of the clamps (record 16_00_730_730_podbíječka_pušl_podbíječka).

It was clear from the comparison that the stresses values do not only depend on the speed of passing vehicles, but also on the type of vehicle and its load.

A decrease in the maximum values of equivalent stresses was found when comparing measurements 10/2016 and 06/2017. The reason for this change is probably the grinding of the rails, which was performed in May 2017.

By comparing the stress values found for the 471 series vehicles (similar speeds, same direction of ride), it can be concluded that when the traction unit was engaged at the rear, the stresses found at the clamps were higher than when the front traction unit was arranged. The highest values were found on the front axle of the traction vehicle.

For the 854 series of vehicles, it is not apparent that the location of the traction unit in the train would affect the stresses results.

7.3.2 Identification of vertical wheel and transverse guiding forces

6 1-LY11-1.5/120 strain gauges with a nominal resistance of 120 Ω connected to the Wheatstone bridge + 6 compensating strain gauges on the plate are glued to the rail web – see Fig. 7-9.

Fig. 7-9: Location of strain gauges for Y and Q measurements

Y - strain gauges at the same distance from the neutral axis of the rail, calibration with a hydraulic spacer bar, measured values in mV / V from the measuring control panel converted to kg, resp. kN. The values were found in the range of -42 kN to 24 kN, it was found that if in a number of vehicles 471 the driving vehicle is located at the rear, then higher values of transverse guiding forces are derived.

Q - strain gauges placed in the neutral axis of the rail, due to the operation it was not possible to perform the calibration, the values are no longer used.

7.3.3 Identification of vertical and transverse displacements

Measurements of rail strip displacements relative to sleepers were performed. A total of four resistance sensors were used to measure rail displacements on the sleeper, two sensors for measuring vertical movements, two sensors for measuring transverse rail movements, namely the NOVOTECHNIC TR50 sensors. Both non-elevated and elevated rail strip were measured - see Fig. 7-10 and Fig. 7-11. The sensors were connected to the measuring amplifier HBM DMC Plus (where the analog recording was digitized at the same time). Digitized voltage records were registered to a PC via the HBM Catman SW. The sampling frequency for the measurement was 600 Hz.

Fig. 7-10: Location of displacement sensors

Fig. 7-11: Detail of the location of displacement sensors

An example of a measured record is shown in Fig. 7-12.

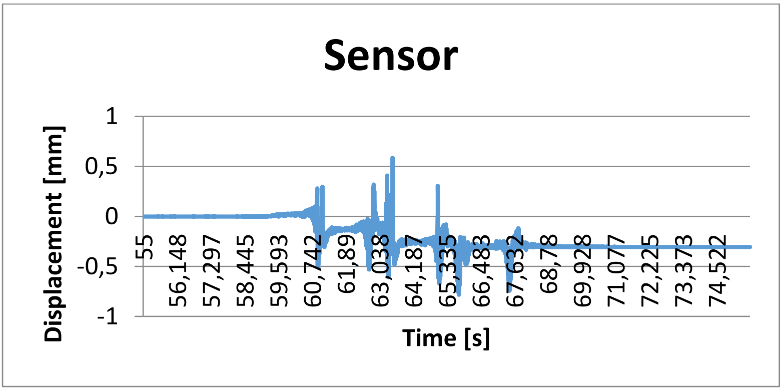

Fig. 7-12: Rail displacement record

The maximum values of transverse displacements reached 0 mm to 0.71 mm, the maximum values of vertical displacements reached 0.24 mm to 0.61 mm. The minimum values of transverse displacements reached -0.19 mm to -0.82 mm, the minimum values of vertical displacements were -0.04 mm to -0.88 mm.

The vertical fatigue limit is ± 1 mm, the maximum detected 1.2 mm.

The transverse fatigue limit + 0.6 / -0.2 mm was repeatedly exceeded. Indication of excessive loading of the clamps, which is in accordance with the conclusions of the fractographic analysis.

7.3.4 Evaluation of fatigue damage

The evaluation of fatigue damage is demonstrated on the basis of experimental measurement of stress on specific clamps located in ŽST Kolín (October 2016). As part of the measurement, the passage of 19 load sets was identified. The measurement was performed over a period of 4 hours (12:30-16:30). The basis for the evaluation of fatigue damage / service life was, in accordance with the methodology, records of stresses on specific clamps from train sets (considered representative) transformed according to HMH hypothesis to reduced stress, static preload values given by clamping tightening and fatigue curve.

The evaluation for fatigue was performed in the following steps:

1) Identification of static prestress and adjustment of stress records from load sets by this static prestress.
2) Evaluation of transformed stress records using the two-parameter method of rain flow RF 2D - use specialized SW.
3) Transformation of the RF 2D matrix using Goodman's criterion into a 1D histogram with zero mean.
4) Determination of partial damage of individual sets - Palmgren-Miner hypothesis – see Fig. 7-13.

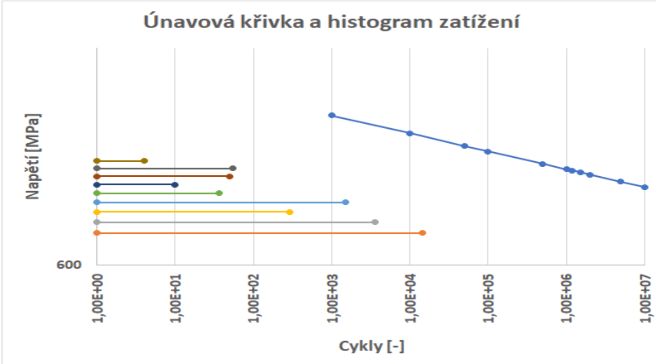

Fig. 7-13: Fatigue curve and load histogram

5) Evaluation of service life for the reference measurement time.
Based on the above calculations, the total service life of the clamp was set at 1.75 years. This correlates very well with the actual service life of the clamps in the given place (approx. 2.5 years).

7.3.5 Acceleration evaluation

Acceleration measurements were performed. An inductive acceleration sensor HBM B12 / 500 was used for the measurement, which was attached to the base of the rail (non-elevated rail strip) - see Fig. 7-14 and Fig. 7-15. The sensor was connected to the measuring amplifier HBM DMC Plus (where the analog recording was digitized at the same time). Digitized records were registered to a PC via the HBM Catman SW. The sampling frequency for the measurement was 600 Hz.

Fig. 7-14: View of the measuring point

Fig. 7-15: Detail of acceleration sensor location

The results are recorded graphically - see Fig. 7-16, compared with the results of previous measurements. The maximum value of acceleration was measured 21.53 g, the minimum value was then measured -25.34 g. The accelerations are comparable with the results obtained in the dissertation [6] for the same type of fastening, i.e. W14.

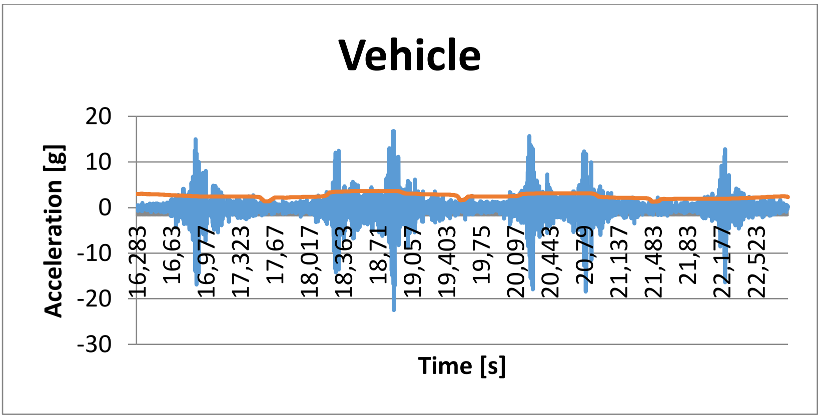

Fig. 7-16: Recording of vehicle acceleration, including RMS display

From the records, the effective values of the RMS acceleration were calculated in the NI Diadem 2014 program, which have a greater telling value of the energy content of the acceleration than the local maxima - see the red curve in Fig. 7 16. The maximum value of RMS acceleration was calculated at 4.95 g and the minimum value of 0.38 g. The comparison can be made with the values of effective acceleration in the vertical direction on the rail specified in ČSN EN 50125-3, which is 280 m/s^2. The measured values were smaller than the values defined by the standard.

Records from the time domain were converted to the frequency domain. FFT was used, signal conversion was again realized in the program NI DIAdem 2014. A sample result is shown in Fig. 7-17. It was clear from the results that the higher the speed, the higher the maximum values to higher frequency spectra. The aim of this evaluation is to determine the frequency bands of slip waves, or to reveal the indication of possible faults.

Slip waves were found in the arc, at distances of individual waves of about 6 - 8 cm. From the knowledge of the distance of individual waves and the speed of vehicles, the frequency bands of slip waves were calculated. A calculation considering some simplification in the form of uniform motion was also used in [6]:

$$v = \frac{s}{t} \rightarrow t = \frac{s}{v} \rightarrow f = \frac{1}{t} \qquad \text{[Hz]}$$

Where v is the vehicle speed and s is the wavelength of the defect.

It was found that the peak acceleration values in the frequency domain coincide with the calculated slip wave bands.

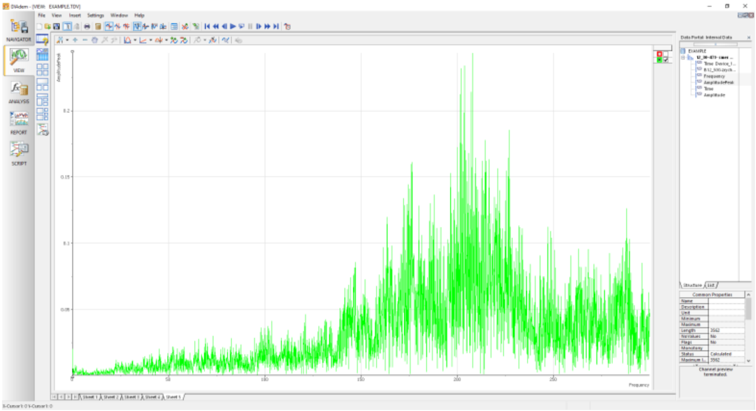

Fig. 7-17: The result of the FFT analysis of the acceleration record when the vehicle passes

An FFT analysis was then performed from the effective power density of the RMS acceleration. Both steps were implemented using the NI DIAdem 2014 program. If the values given in Annex C of ČSN EN 50125-3 are compared with the values of the FFT analysis of effective acceleration power densities, the values found are smaller than the values required in the standard.

8 Conclusion

The properties of the Skl 14 clamps were verified, no discrepancies with the requirements were found.

A methodology was proposed, within which the evaluation criteria and the way of their use were specified. Verification and at the same time demonstration of the use of the methodology was presented on the measured section near the Kolín railway station (line 502A Kolín - Nymburk), where the line is located in a small radius curve and where the clamp arms break. Based on the performed measurements and evaluations in accordance with the proposed methodology, the causes of clamp failures were identified (large transverse displacement of the outer arms of the flexible clamps, high fatigue load).

The essence of the findings according to the methodology were therefore high transverse displacements, which due to cyclic loading (fatigue) led to failures of the clamp arms. The measurement was performed directly in the track and the resulting values were confronted with the limit value of transverse displacements of the arms 0.6 / -0.2 mm. The detected values ranged from -0.82 to +0.71 mm. Another evaluation criterion was the fatigue evaluation itself, which proved with very good agreement the low service life of the clamps under the given loading conditions. The service life was set at 1.75 years (real value is 2.5 years).

Within the methodology, further detailed analyses were performed leading to the above-mentioned facts. It was mainly a fractographic analysis of the fracture surfaces of the clamps, where it was found that these are fatigue failures (there is no plastic behaviour). From the point of view of fatigue damage, the high static preload caused by tightening the clamps to the prescribed tightening torque also plays a role. These stresses at the fracture site reach approx. 990 MPa. The experimentally obtained values were confronted with FEM calculations, where they show good agreement (difference up to 20%).

As additional measurements that can identify the unsatisfactory condition of the clamps (e.g. in terms of geometry of the track), the measurement of the clamping force and its evaluation was performed. Within this measurement, two methods of measurement were implemented (according to ČSN EN 13146-7, Vossloh device). The measurements were focused on clamps with different degrees of corrosion. As a result, it has been found that when the wire thickness is reduced below 12 mm and the clamp weight is reduced below 470 g, the clamps must be replaced.

Within the dynamic measurements using strain gauges located on the rail web, vertical Q and guiding forces Y were identified, which in the context of FEM calculation may indicate a high load (resulting from the overall track geometry, line speed and traffic load).

Another evaluation criterion was the frequency analysis of the acceleration of the rail foot. The prescribed limit values for effective acceleration in the vertical direction on the 280 m / s2 rail were not reached.

9 Benefits of the dissertation

The work presents a comprehensive methodology for evaluating the condition of flexible clamps SKL14 in operated lines. This methodology combines different aspects of evaluation that can be flexibly combined. This makes it possible to identify the current state of the clamps, or the whole fastening system according to specific symptoms. This is one of the main benefits of the methodology - to identify the emerging or established failure according to the symptoms.

The work also provides an extensive overview of current legislation and the resulting evaluation criteria, which are confronted with experimentally obtained data.

The work identifies the basic mechanical and chemical properties of clamps (newly, for example, defines the fatigue curve found during pulsating tensile loads converted to alternating stress).

A very important part of the work is the chapter devoted to the verification of the methodology, where various practical procedures leading to the acquisition of the required evaluation characteristics are presented.

Part of the work is also devoted to the FEM model of the clamp and the possibility of using numerical analysis of the behaviour of the clamp, a high degree of agreement between FEM results and experimentally obtained data was demonstrated.

Literature

[1] Technické podmínky dodací č. 1/SŽDC/07 pro pružné svěrky Vossloh. 1.1.2008.

[2] D. Veselý, A. Kalendová: Anticorrosion efficiency of ZnxMgyAl2O4 core–shell spinels in organic coatings, Progress in Organic Coatings, Volume 62, Issue 1, March 2008, Pages 5–20.

[3] Vydavatelství Úřadu pro normalizaci a měření, Praha; ČSN 03 8102: Vyhodnocování korozních zkoušek podle korozních úbytků; 21. 5. 1986., zrušena 1. 1. 1995.

[4] ČSN EN 10089. Oceli válcované za tepla na zušlechtěné pružiny: Technické podmínky dodací. Praha: Český normalizační institut, 2006.

[5] VOSSLOH. VOSSLOH [online]. 2019 [cit. 2019-03-15]. Dostupné z: https://www.vossloh.com/01_product_finder/VFS/System-W-14/Vos_Produktbroschuere_W14_EN.pdf

[6] Ing. Vladimír Tomandl: Experimentální analýza vybraných systémů kolejnicových upevnění. Brno. 2016. 240 s., 180 s. příl. Thesis. Vysoké učení technické v Brně, Fakulta stavební, Ústav železničních konstrukcí a staveb. Vedoucí práce prof. Ing. Jaroslav Smutný, Ph.D.

[7] Adamek; Podložky pod ložnou plochou pražce a jejich pozitivní vliv na geometrickou polohu koleje; VTS ČD č. 21/2006

[8] Správa železniční dopravní cesty, státní organizace, SŽDC S3, Železniční svršek, účinnost od 1. října 2008 ve znění změny č. 1 (účinnost od 1. října 2011), změny č. 2 (účinnost od 1. října 2014), změny č. 3 (účinnost od 1. března 2019).

[8] AUER, Florian, Rodolphe POTVIN, Otto PLÁŠEK a Miroslava HRUZÍKOVÁ. Podpražcové podložky v koleji. NŽT - Nová železniční technika. 2015, 2015(1), 21 - 28.

[9] České dráhy, s. o., divize dopravní cesty, o. z., Obecné technické podmínky pro pružné svěrky a spony, č. j. 60 788 / 99 – O13. 2000.

Own publications

9.1 Publication activities of the doctoral student related to the topic of the dissertation

[1] PĚTIOKÝ, Marek, Eva SCHMIDOVÁ, Petr HANUS a Bohumil CULEK. METALOGRAFIE PRUŽNÉ SVĚRKY SKL14. Hradec Králové: ISBN 978-80-87952-07-8, 2014.

[2] PĚTIOKÝ, Marek, Eva SCHMIDOVÁ, Bohumil CULEK a Petr HANUS. Problems of the level crossings. In: International Congeres on Advanced Railway Engineerings: Proceedings. Istanbul: -, 2015, s. 102-106.

[3] PĚTIOKÝ, Marek, Culek BOHUMIL, Kalendová ANDRÉA a Kohl MIROSLAV. Zkoumání korozní odolnosti pružných svěrek Skl14. In: SEMDOK2015. Žilina: Žilinská univerzita / EDIS, 2015, 157 - 160. ISBN 978-80-554-0981-8.

[4] PĚTIOKÝ, Marek, Schmidová EVA, Hanus PETR a BOHUMIL. Fraktografie pružné svěrky Skl14. In: JUNIORSTAV 2015. Brno: VUT v Brně, 2015, s. 183. ISBN 978-80-214-5091-2.

[5] PĚTIOKÝ, Marek, Bohumil CULEK, Andréa KALENDOVÁ a Miroslav KOHL. The Investigation of the Corrosion Resistance of the Tension Clamps Skl14. In: Materiálové inžinierstvo: Materials engineering : The Scientific Journal of the Faculty of Mechanical Engineering University of Žilina, Slovak Republic. Žilina: Žilinská univerzita, Strojnická fakulta, 2015, s. 95-100. ISSN 1335-0803. Available from: http://ojs.mateng.sk/index.php/Mateng/article/view/168.

[6] PĚTIOKÝ, Marek, Bohumil CULEK, Petr Vnenk. Měření napjatosti pružných svěrek v provozu. Brno: VUT Brno, 2018.

9.2 Publication activities of the doctoral student indirectly related to the topic of the dissertation

[I] Pětioký, Jirků; Legislativa vztahující se k interoperabilitě a připravované změny technických specifikací pro interoperabilitu subsystému infrastruktura; 10. Fórum koľajovej dopravy; Bratislava; 03/2014

[II] Pětioký, Čech, Souček, Tomandl; Požadavky TSI týkající se mostů a tunelů a zkušenosti z posuzování železničních mostů a tunelů na požadavky interoperability; Železniční mosty a tunely 2014; 23. 1. 2014; sborník str. 63 – 68.

[III] Tomandl, Pětioký, Felgr, Jirků, Posuzování subsystému Infrastruktura dle TSI ve fázi projektu, Vědeckotechnický sborník ČD č. 35/2013.

[IV] Felgr, Jirků, Tomandl, Pětioký, Zkušenosti z posuzování interoperability významných staveb železniční infrastruktury, Železnice 2012, 29. 11. 2012.

[V] PĚTIOKÝ, Marek (spoluautor). Autor pasáží věnovaných železničním svršku a spodku VZO a MZO, Y/Q TEST. 2013, č. 0.

[VI] PĚTIOKÝ, Marek. Posuzování stavby Elektrizace trati Zábřeh na Moravě - Šumperk. Y/Q TEST. 2014, č. 1.

10 Abstract

The thesis analyses problems related to tension clamps Skl14, especially corrosive losses of tension clamps material at railway crossings or in tunnels and their influence on the clamping force. The aim of this work is to find a methodology that would lead to a clear decision about replacement, eventually leaving flexible clamps in the track and analysing the causes of problems.