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VERIFICATION OF FATIGUE STRENGTH OF RAILWAY AXLES IN ACCORDANCE WITH STANDARDS EN.

OVĚŘENÍ ÚNAVOVÉ PEVNOSTI ŽELEZNIČNÍCH NÁPRAV PODLE EN.

Abstract

Calculation procedure of long term fatigue of railway axles is defined in the standards EN 13103 and EN 13104. Values of fatigue strength that are used in calculation are verified by fatigue tests. Standards EN 13103 and EN 13104 defined both tests on the small test pieces with dia 10 mm as full scale tests. Test stresses are measured by strain gauges. In transition parts between wheel seat and shaft of the axle are stresses concentrated. Measured values of stresses are significant higher than values calculated by standard beam theory. Evaluation of test results in the light of demands of standards. Influence of fretting corrosion on the fatigue life of the axle.

Abstrakt

Postup výpočtu dlouhodobé pevnosti železničních náprav je definován v normách EN 13103 a EN 13104. Hodnoty únavové pevnosti použité ve výpočtu jsou ověřovány únavovými zkouškami. Normy EN 13260 a EN 13261 předepisují zkoušení jak na malých vzorcích průměru 10 mm, tak na vzorcích ve skutečné velikosti. Zkušební napětí jsou měřená tenzometry. V oblastech přechodu mezi sedlem a dříkem nápravy dochází ke koncentraci napětí. Naměřená napětí potom výrazně překračují hodnoty vypočtené klasickou teorií nosníků. Interpretace výsledků zkoušek únavy s ohledem na požadavky norem. Vliv třecí koroze na únavovou životnost v oblasti sedla nápravy.

1 INTRODUCTION

From the year 2004 there are applied new railway standards for calculation, production and tests of railway axles and wheels EN 13103, EN 13104, EN 13260 a EN 13261. These standards contains demands that were also in the older UIC leaflets but for better safe in the service were newly defined conditions that leads to higher level of service safety. Main of them is verification of fatigue properties on full scale axles.

For the fatigue test on the small samples are used samples with diameter of 10 mm, there are tested minimally 15 pieces with smooth surface and min. 15 pieces with notch. Test piece is defined by standard EN 13261 [2] and test procedure and evaluation is defined by standard ISO 12107 [3]. Evaluation of fatigue limit is made by Staircase method.

Aim of the test is not only to estimate fatigue limit of smooth pieces RfL and fatigue limit of notched pieces RfE with probability of crack 50 % but also estimation of coefficient q = RfL/RfE. This coefficient is very important for estimation of safety factor. Safety factor for calculations of axles is given by standard EN 13103 and EN 13104 and is equal 1, 2 for steel grade EA1N. Safety factor value for another type of steel in accordance with standard is for steel EA4T equal to: S=1,2*q(other steel grade)/q(steel EA1N)=1,2*1,63/1,47=1,33.

Basic safety and material coefficients are than used in calculation of strength of the axle in accordance with standard EN 13103 [1].

2. VALUES TO BE ACHIEVED

Values to be achieved are prescribed in the standards EN 13261 and EN 13260.

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Table 1: Fatigue values for full scale test pieces of railway axles [2], [4] .

Steel grade	F1-(MPa) Free surface in accordance with PrEN 13261 (MPa)	F3-(MPa) Wheel seat in accordance with prEN 13260	F4-(MPa) Wheel seat in accordance with prEN 13260
EA1N	≥200	≥120	≥ 110
EA4T	≥240	≥145	≥ 132

Where: F1 ... Fatigue limit on the body surface of the axle
F3 ... Fatigue limit on the wheel seat surface in the assembly of the axle and wheel

3. TEST OF THE AXLE.

Service loads of the railway axle create bending moment. The stresses that correspond this bending moment are in some cross sections measured and checked with the aid of calculations. Than there are checked if maximal permissible stresses in particular cross sections are not higher than allowed values.

The parts of the axle where values of stresses are highest are in the seat and in transition part from the seat to axle shaft. These parts are tested for 10 million cycles. For saving of time and energy during the test there are used resonance test machines.

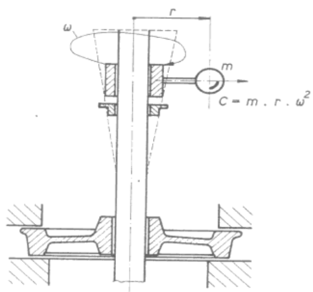


Fig. 1 – Principle of the resonance testing machine.

Principle of such machine is shown on the picture 1. On the one end is test piece connected with basement and on the second end is rotating eccentric mass mounted. During rotation of eccentric mass rise in the tested axle rotating bending moment that well simulates loading of the axle during service. Load of the test piece is dependent on mass of test piece and on speed of rotation that can be up to 25 Hz. Test is checked and controlled by strain gauges that shown real values of stresses. There is mostly used full bridge connection of strain gauges that is shown in Figure 2.

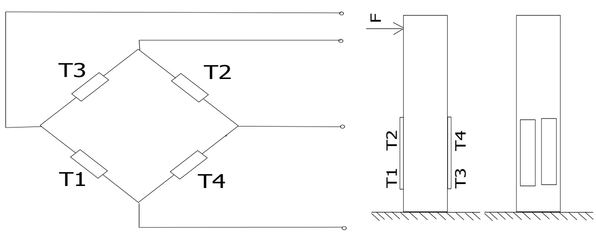


Fig. 2 - Connection of strain gauges into full bridge on the tested axle.

When strain gauges are glued on and test piece is fixed to the foundation there is checked a critical point of construction by statically loads. In this critical point the strain gauges are glued on and during dynamical test the defined values of stresses in this point are checked.

Static loading of the railway axle is applied by hydraulic cylinder that applied force F_{kal} on the upper free end of the axle. From this loading is obtained relation of stress on the loading force $\sigma = f(F_{kal})$. Than is made test when the axle is loaded by rotating bending moment for 10 million cycles so, that in checked cross section is stress in accordance with demand of standard.

In the case of driving motion axle with hole there is in the critical cross section modulus W defined as:

$W = \pi * D^3 * [1- (d/D)^4] / 32 \quad [mm^3]$ (2)

Where : D - outer diameter of the axle, d - diameter of the hole, and necessary calibration static force F_{kal} , that is applied in distance L is than defined :

$F_{kal} = \sigma b * Wb / L \quad [N]$ (3)

where: L - distance from calibration force F_{kal} to calculated cross section, σb - bending stress, Wb - section modulus for given diameter.

From this calibration force we can obtain stress in the area where the strain gauges are glued on:

$\sigma_{DMS} = M / W = F_{kal} * L_{DMS} / W_{DMS} \quad [MPa]$ (4)

where: σ_{DMS} - stress in the place of strain gauges, W_{DMS} - cross section modulus, L_{DMS} - distance between calibration force Fkal and strain gauge.

For tests in the areas with stress concentrations there were used strain gauge chains, for instance HBM 1-KY11-4/120 in transition parts from axle shaft to wheel seat.

4. STRESS CONCENTRATION

During tests of railway axles and various steels for axles that are recommended in the European standards EN 13261 and EN 13260 there was also tested influence of the form and design on the stress concentration factor. Also were tested some methods for improving of surface properties of the axles.

Great attention was paid to places with changes of diameters in which stress concentration is generated. Stress concentrations were calculated from measured values of stresses and compared with calculated values of stress concentration factors. It shows that calculated values are commonly smaller than measured ones.

Calculated values of stress concentration factor were calculated in accordance with standards EN 13103 or DIN 743.

Stress concentration factor is defined as relation between measured and nominal stress σ_n:

$Kt = \sigma_{DMS} / \sigma_n$ (7)

Value of this factor is depended on diameter relation, filet radii, design of transition part and so on.

For instance for railway axle with ratio D/d = 194 / 173 = 1,121 and filer radii r = 75 mm is value of stress concentration factor in accordance with DIN 743 is Kt = 1,107 and measured value for the same axle is Kt = 1,147.

There was measured stress with strain gauges on the axle of the older type of freight car. For transition part with ratio D / d = 185 / 160 = 1,15625 and fillet radii r = 75 the maximal value was 200 MPa for cross section where calculated value of stress was only 160,0 MPa. For this case the stress concentration factor is Kt = 1,243.

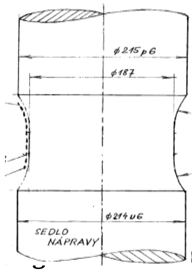
There were measured with strain gauge chains more transition parts of various types of railway axles as is shown in the **table 2**:

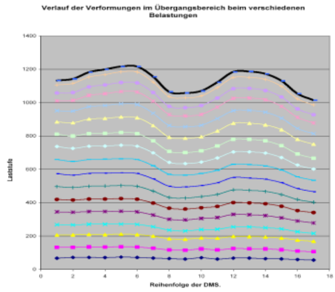
D [mm]	d [mm]	D/d [-]	R [mm]	σ_{DMS} [MPa]	σ_n [MPa]	Kt [-]
185	160	1,15625	75	203	160,9	1,26
163	154,5	1,055	20	156	148	1,55
214	188,02	1,1382		255,6	206,2	1,24
236	233,3	1,011	75	172	136	1,27

Table 3: Examples of measurements in transition part of railway axle of driving car.

Distance of strain gauges to seat edge in mm	5	10	15	20	25	30	35
σ [MPa]	179	178	186,5	192,5	199,5	188,5	177

For this measurements was used type 1-KY11-4/120 of strain gauge and in transition part there was 19 points measured. Measured length of this strain gauges is 4 mm. Gauge factor of this strain gauges is K = 1, 99.





centration in the transition part of the axle.

Table 4 : Comparison of measured and calculated strain concentration factors.

Ratio D/d	Kmeasured	Kcalculated K = A + 1 , X=r/d , Y = D/d , A= [(4-Y*((Y-1)] /5*(10X) $^{(2,5X-1,5-0,5Y)}$
1,156	1,25	1,05
1,15	1,22	1,02
1,144	1,23	1,12
1,121	1,133	1,1

5. CONCLUSION

There were made a lot of measurements with measurement apparatus Spider 8/30 that can take signals up to frequency 1200 Hz. This measurement apparatus has 8 data channels and there is possible to measure also dynamic signals. For evaluating of measured signals there is Software CONMES used.

Measurement with strain gauge chains gives possibility to exactly find the places where stress values are highest and where cracks on the railway axle surface can be initiated.

Knowing critical place on the railway axle can be fatigue properties of body surface (F1 – in accordance with EN 13261) and surface of seat (F3 - in accordance with EN 13260) checked in one test on the one piece.

REFERENCES:

[1] EN 13103: Železniční aplikace – Dvojkolí a podvozky – Nepoháněné nápravy – Metody konstrukce.

[2] EN 13261:Prosinec2004 - Železniční aplikace – Dvojkolí a podvozky – Nápravy – Požadavky na výrobek

[3] ISO12107 Matallic materials – Fatigue testing – Statistical planning of analysis data.

[4] EN 13261:Prosinec2004 - Železniční aplikace – Dvojkolí a podvozky – Dvojkolí – Požadavky na výrobek

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