

The use of fatigue tests in the manufacture of automotive steel wheels.

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Abstract. Production for the automotive industry must be particularly sensitive to the aspect of safety and reliability of manufactured components. One of such element is the rim, where durability is a feature which significantly affects the safety of transport. Customer complaints regarding this element are particularly painful for the manufacturer because it is almost always associated with the event of accident or near-accident. Authors propose original comprehensive method of quality control at selected stages of rims production: supply of materials, production and pre-shipment inspections. Tests by the proposed method are carried out on the originally designed inertial fatigue machine. The machine allows bending fatigue tests in the frequency range of 0 to 50 Hz at controlled increments of vibration amplitude. The method has been positively verified in one of rims factory in Poland. Implementation resulted in an almost complete elimination of complaints resulting from manufacturing and material errors.

1. Introduction

Durability and strength of car wheels are important characteristics affecting safety [1]. Unfortunately awareness of this fact can be observed only in certain industries, such as aviation and in motor racing, where the safety culture is valued very highly. Also good examples can be given from railway industry. For instance, [2] outlines methods and equipment for in-service inspection of wheel-sets in maintenance stations and potential of a testing station for automated ultrasonic inspection of rim and disk of wheels at dismounted wheel-sets in.

Qualified and experienced technicians visually check the complete wheel prior to installation using if in doubt, endoscopic and penetration techniques. The total number of hours of driving to specific wheels is monitored. The wheel rims showing signs of fatigue or damage are scrapped and replaced with a new one. Unfortunately, this strict control procedures are not common among users participating in normal road traffic and price is still the main criterion for selection of wheels.

Existing guidelines for wheels tests are not obligatory for manufacturers and concern rather the development of new types of wheels that before industrial production are subjected to various types of endurance tests and approvals [3- 9].

However, already in the process of production of wheels is hard to find a comprehensive, reliable quality control system, enabling quick answer about the quality of the currently produced batches.

This paper proposes a system of quality control wheel on selected stages of production with the use of accelerated fatigue tests. The proposed system includes control at the stage of materials delivery (preliminary tests – supply control), welding rims (tests of welded joints quality) and pre-shipment inspection (testing of the finished product).



Preliminary tests are intended to determine whether the purchased material (steel sheets) adheres to the standards and requirements of fatigue strength certificates, i.e., whether the material used for the production will not be destroyed by fatigue before the specified number of load cycles.

Tests during the manufacturing process relate to the verification of the fatigue life of samples of welds performed in the process. Welds can be performed either manually or using a welding robot. Tests are used to evaluate the durability and quality of the weld but it can also be used to verify the competence of the welder. Pre-shipment tests concern destructive testing of rims. Its aim is - like testing during the production process - assessment of the durability of welded connections but the samples are taken from the finished product.

2. Testing stand

Tests are carried out on originally designed inertial fatigue machine (figure 1 and figure 2). The machine allows bending testing of flat specimens (figure 3) at frequencies from 0 to 50 Hz with controlled stepwise amplitude excitations equal to 1, 2 or 3 mm. The samples have a notch to force the initiation of fatigue failure in a certain position of the notch location. Experiment involves fixing the specimen in the machine spindle, determination the frequency and amplitude of the spindle (forcing vibrations of the sample) and continuous recording of different variables characterizing the process of vibration from the beginning of the experiment to failure. By using a multichannel measurement system the following parameters are measured:

- the relative amplitude of the vibration (displacement) of the upper part of the sample - the eddy current sensor,
- the relative amplitude of the vibration (displacement) of the lower part of the sample - the eddy current sensor,
- absolute amplitude (acceleration) of the spindle - piezoelectric sensor,
- phase of vibration - reflective sensor,
- numbers of cycles to failure - optical sensor.

The amplitude of the vibration of the upper part of the sample can be changed without changing the frequency by attaching to it the additional weights.



Figure 1. General view of testing stand.

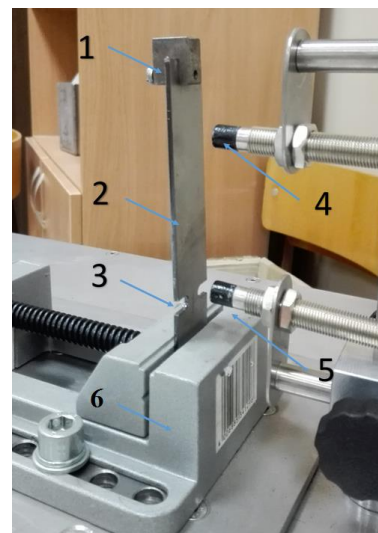


Figure 2. View of testing stand (1 – additional weight, 2 – (specimen) sample 3 - notch, 4 upper eddy current sensor, 5 - lower eddy current sensor, 6 - spindle).

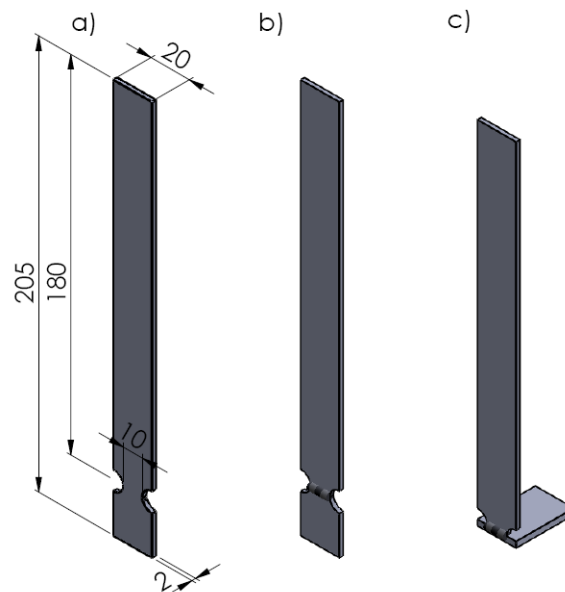


Figure 3. Examples of test samples used in the presented method, a) obtained from sheet metal, b) welded, c) a combination disc and wheel rim fillet weld obtained from the wheel rim.

3. Preliminary tests – control of purchased material

The aim of the test is to evaluate selected mechanical properties (bending strength) of the steel rims. The sample (figure 3a) cut from the sheet supplied for the production is subjected to vibrations of such amplitude that causes in a notch stress corresponding to the strength of the test steel. Number of cycles to failure is recorded. The indicative value of the flexural fatigue strength of ordinary quality steel subjected to mutually pulsating load $k_g = (0.2-0.35) R_e$, wherein R_e - yield stress (approximately 230MPa). Destruction of the sample (for most types of steel used in the manufacture of wheels) should not take place before the end of 10^7 cycles.

The amplitude of the vibration causing required stress can be calculated from equation (1).

$$f = \frac{2l_{cz}^2 k_g}{3Eg} \quad (1)$$

where:

f - required amplitude of the sample (upper end) [m],

l_{cz} - active length of the sample [m],

k_g - flexural fatigue strength of steel [Pa],

E - Young's modulus [Pa],

g - sample thickness [m].

Assuming $l_{cz} = 180\text{mm}$, $k_g = 70\text{MPa}$, $E = 200\text{GPa}$, $g = 2\text{ mm}$ the result $f = 3.78\text{mm}$ is obtained. Thus forcing vibration of sample with an amplitude equal to 3.78 mm, stress obtained in the vicinity of the notch is equal to the fatigue strength of the considered steel. Destruction of the sample before the 10^7 cycles means that the steel to be used for the production of wheels does not meet the strength requirements and cannot be used for further production. Due to the fact that this test is time-consuming, it is done with a maximum frequency of 50Hz (in earlier studies, it was found in the range of 0-50 Hz the fatigue life does not depend on excitation frequency) and takes about 50 hours.

4. Tests in production process

The test aims to verify the durability of the weld made in the technology that will be used later in the production process. Sheet to be used for the production are cut and then welded back in the given technology, either manually or using a welding robot. Prepared sheet is cut to a sample size (figure 3b). The sample is subjected to vibrations of resonant frequency (in order to speed up the course of the test) until its destruction. Positive result is observed then, when the destruction of the samples occurs outside the weld. For samples with dimensions given in this paper resonance frequency is around 30Hz.

The second test focuses on testing the strength of the samples to bending by simulating the load wheels when turning, in accordance with Annex 6 to Regulation 124 of the European Economic Commission of the United Nations (UNECE) - Uniform provisions concerning the approval of wheels for passenger cars and their trailers. In this test lateral forces acting on the wheel when driving around a corner are simulated. Four samples are tested, two at 50% and two at 75% of the maximum bending moment which is calculated according to the formula (2).

$$M_{b\max} = S \cdot F_V \cdot (\mu \cdot r_{\text{dyn}} + d) \quad (2)$$

where

$M_{b\max}$ - maximum bending moment [Nm],

F_V - maximum wheel load capacity [N],

r_{dyn} - dynamic radius of largest tire recommended for rim [m],

d - offset [m],

μ = coefficient of friction ($\mu = 0.9$),

S = safety factor ($S = 2.0$).

Assuming, for example, $F_V = 3350\text{N}$, $r_{\text{dyn}} = 0.208\text{m}$, $d = 0.045\text{m}$, $\mu = 0.9$ and $S = 2$, $M_{b\max} = 1620\text{Nm}$. Such moment acts on the real rim causing the stress k_m to be mapped on the test sample. Simulation studies were carried out to determine its value (figure 4) with result $k_m = 150\text{MPa}$.

Using equation (1) amplitude $f = 8.1\text{mm}$ is obtained and accordingly, for 50% and 75% of the maximum bending moment $f_{50\%} = 4.05\text{mm}$ and $f_{75\%} = 6.1\text{mm}$. The minimum number of cycles are shown in table 1.

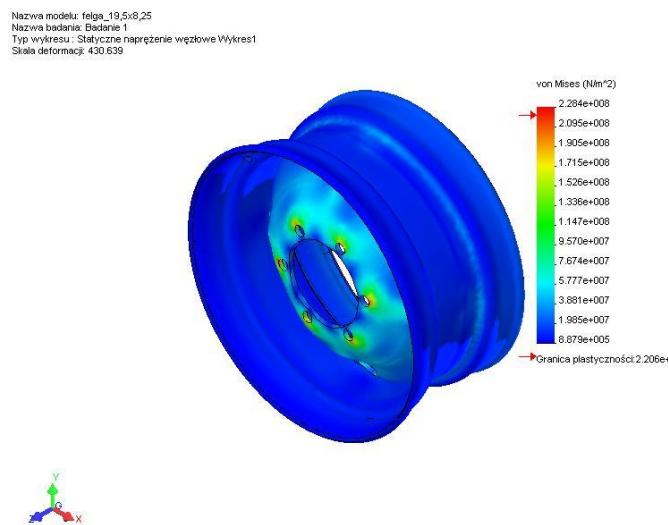


Figure 4. Simulation of the stress distribution in the rim under the effect of the bending moment.

Table 1. The minimum number of cycles, which cannot cause damage to equipment [9, 10].

Vehicles category	steel wheels	
	passenger cars	trailers up to 750kg
min. number of cycles by 75% of M_{bmax}	$6 \cdot 10^4$	$2 \cdot 10^4$
min. number of cycles by 50% of M_{bmax}	$6 \cdot 10^5$	$2.3 \cdot 10^5$

5. Tests of the finished product - pre-shipment inspection

Tests of the finished product takes place analogously to the test in the production process. Accordingly, the sample cut from the finished rim (figure 3c) is placed in the fatigue machine where vibration at the resonant frequency of the sample are forced. A positive test result is observed when the sample does not occur the destruction of the joint. The proposed frequency of tests for all production stages are presented in table 2.

Table 2. Frequency of tests in rim production.

Preliminary tests	Production tests	Finished product tests
<ul style="list-style-type: none"> Each delivery: 4 samples cut from two randomly selected sheets. 	<ul style="list-style-type: none"> At each change of technology / welding parameters. After each repair of welding equipment. Each welder at least once a quarter. For each production order, 4 samples with one slotted and welded sheet. 	<ul style="list-style-type: none"> With each batch sent - 4 samples cut from one random wheels.

Table 3. Percentage of negative tests results and customer complaints after 3 and 9 months of the system implementation.

Time after	Preliminary tests	Production tests	Finished product tests	customer complaints
3 months	25%	15%	5%	5%
9 months	0%	5%	3%	2%

6. Conclusions

The described system of quality control has been implemented in one of the rim factories in Poland. The factory produces annually about 1200 rims per month. In the initial phase it has been installed one test stand. The level of customer complaints were about 5% of total production at that time. It should be noted that about half of them was not justified and was due to operational errors of rim's users. During the first three months of the system application, on average 25% of preliminary, 15% of productions and 5% of finished tests gave negative results which resulted in the rejection of batches of materials or even finished products.

Analysis of the causes of the high number of discards showed that:

1 - 85% of negative results on the phase of delivery control (preliminary tests) were generated by only one of three sheets suppliers; it was decided to abandon further cooperation.

2 - 95% of all errors in the phase of production tests were generated by manual welding. Welding robot was responsible for only 5% error and only in preliminary phases of production, when the process of determining the correct welding parameters was still in progress; decision was taken on additional training for welders and changing work organization so as to provide maximum load for welding robot.

After 9 months the number of negative tests results dropped to 0% for preliminary, to 5% for production and to 3% for finished products tests. The number of customer complaints dropped from 5 to 2%. (table 3).

The company positively assessed the effects of the implementation and operation of the developed quality control system. Thanks to its operation it was possible to identify and eliminate the main causes of customer complaints. The system allows to prove compliance with these requirements of ISO9001 standard which relate to control of production processes.

In addition proposed method partially meets the guidelines contained in Regulation No 124 of the Economic Commission for Europe of the United Nations (UNECE) - Uniform provisions concerning the approval of wheels for passenger cars and their trailers and EUWA Standards of March 1992 which inspires confidence of major customers of the company and is reflected in the long-term contracts.

References

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