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POSSIBILITY OF MULTIAXIAL TEST SIMPLIFICATION OF RAIL VEHICLE BOGIE FRAMES

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1. Introduction

A multi-axial loading is usually used in a lifetime experimental testing of rail vehicle bogie frames. A good attainment of experimental test results is commonly achieved by use of many actuators in the same time. These tests are expensive, time-consuming and depended on laboratory equipment. The lifetime of construction is determined by few the most exposed locations, which are given by value and distribution of mechanical stresses. For this reason it is preferable to test only the most exposed parts of construction. The nature of the responses in these locations can be determined by use of FEM analysis and experimental measurements of responses on the traffic load. The load system of the specimen is designed according to obtained information. The question is how much we can simplify (change) the load system of the construction part in the load tests in comparison with loading of structure in operation. The aim of the work is to determine possibility to find a solution for reduction of total number of actuators. A procedure of transformation from triple-cylinder multi-axial test to double-cylinder or single-cylinder test is described. The importance is given on load response accuracy and comparison of both tests. Solution is based on synthesis numerical (FEM) and experimental methods.

2. Specimen design

The specimen is designed according to construction part commonly used in railway vehicle bogie frame. In the selection of node has been taken into account the size, manufacturability and simplicity. Main criteria are listed in the following points:

- **Manufacturability and simplicity** - specimen must be simple to manufacture.
- **Load system** - the specimen design must allow multi-axial loading (the possibility of multidirectional loading or torsion). Single-axial loading must be allowed too.
- **Specimen size** - size is limited by dynamic laboratory equipments (maximum dynamic power performance).
- **Critical place** – the critical place must allow the experimental measurements (enough space for strain gauges). This place must not be affected by welded joint or by other technological notch. The criterion is the possibility of determination an estimation of lifetime by use of the fatigue damage accumulation hypotheses.

Several construction details (commonly used in the construction of the railway vehicles bogie frame) are displayed on the Fig. 1 to Fig. 4.

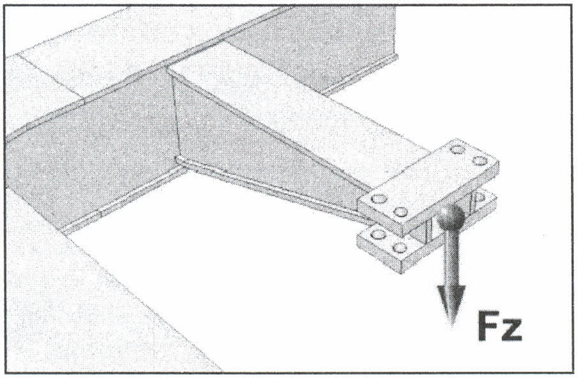

Fig. 1 *Disk brake cantilever beam* [1]

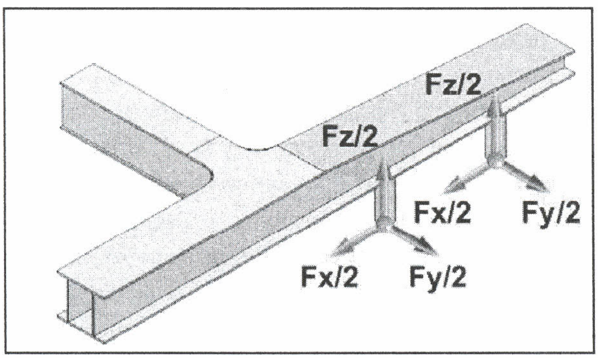

Fig. 2 *Part of longitudinal beam of rail vehicle bogie frame* [1]

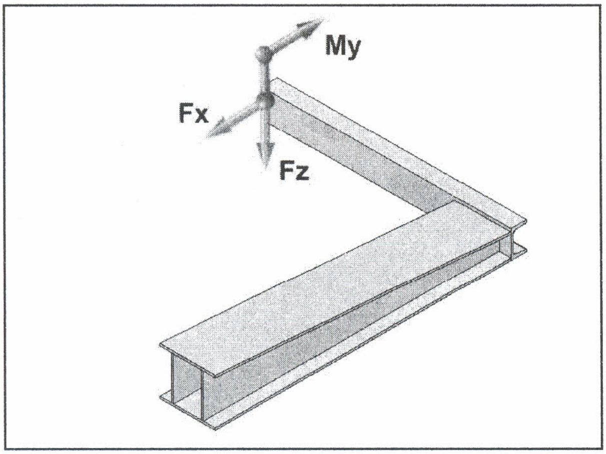

Fig. 3 Connection of longitudinal beam and headstock [1]

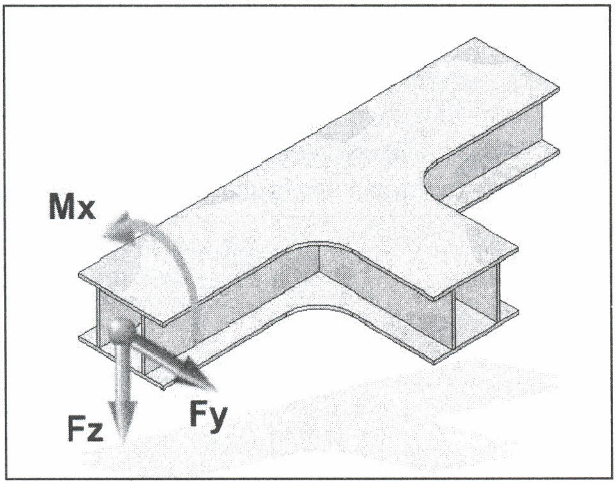

Fig. 4 Connection longitudinal beam with cross beam [1]

Due to possibility of testing (excluded weld connection) the detail of longitudinal and cross beam connection was chosen.

3. Specimen critical places

The critical places (CP) were found on curvature of beams connection. The FEM calculation verified the extreme mechanical stresses in the CP (Fig. 5). The FEM analysis was calculated for multi-axial loading (use of different load modes).

The shape of the beams connection curvature was changed to increase the maximum mechanical stress in the CP. This change decreases a total time of fatigue tests. On this account were different CP shape variants designed (Fig. 6) and FEM analysis was done.

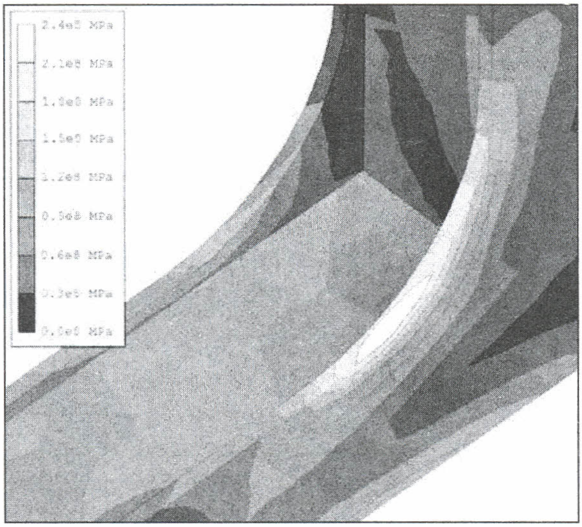

Fig. 5 *An example of main stress (σ_1) in the CP*

The load of specimen in the FEM was same as load for FEM calculation of the original shape. The results from the FEM analysis are shown on the Fig. 7. Due to possibility of maxima stress measurement in the CP the last variant **D** was chosen. A schema of final appearance of specimen is shown on the Fig. 8.

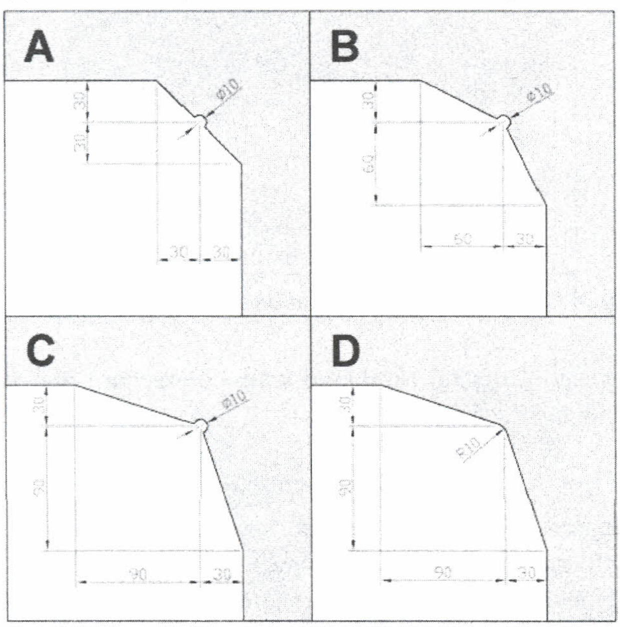

Fig. 6 *Designed variants of critical places*

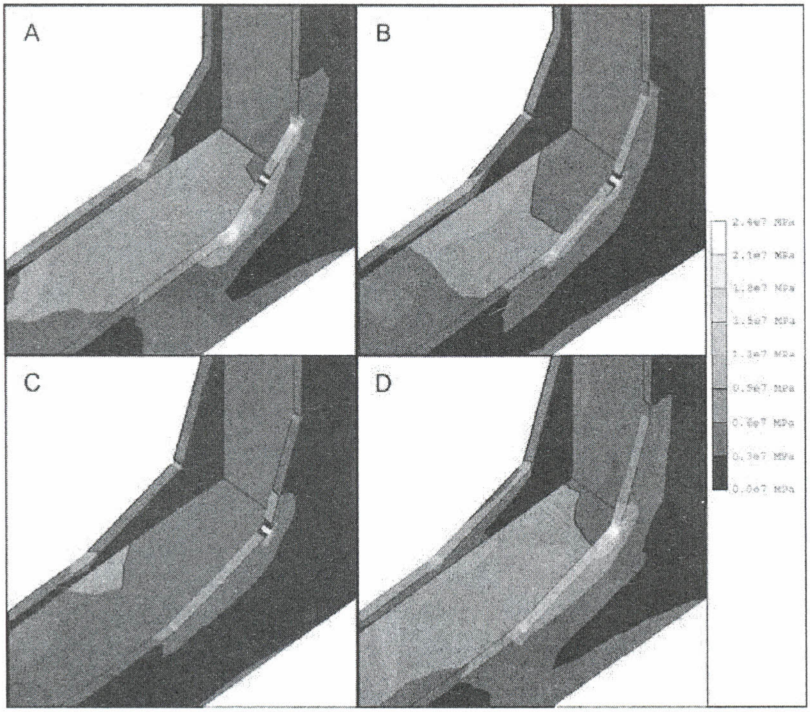

Fig. 7 *FEM analysis results for designed variants*

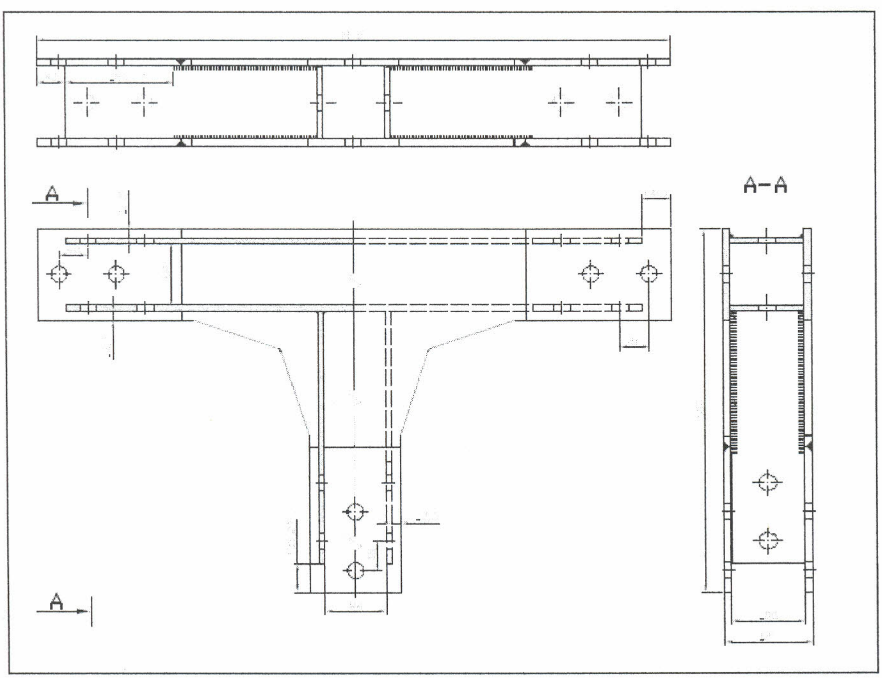

Fig. 8 *Assembly drawing of specimen*

4. Load system of specimen

The load system allows application of three loads together but also allows application of individual load component particularly. Each actuator is used with two joints (Fig. 9). The arrangement is more stable in the pull direction in comparison with push direction.

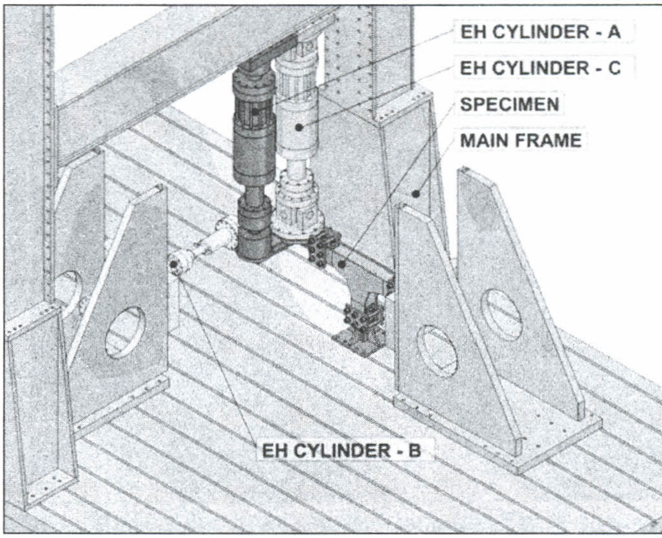

Fig. 9 *Axonometric view on load set*

The connection of actuators joints to specimen is realized by fastening tool (Fig. 10, 11). A management of actuators is described in the Tab.1 and on Fig. 10. This actuator management allows load change between the multi-axial load and one-axial load.

Tab. 1 *System of actuators management*

Loading mode	Z	Y	X	Z + Y + X
C cylinder	$F_C = F_Z$	*Stop*	$F_C = - F_X / e$	$F_C = F_Z - M_X / e$
B cylinder	*Stop*	$F_B = F_Y$	*Stop*	$F_B = F_Y$
A cylinder	$h_A = h_C$	*Stop*	$F_C = F_X / e$	$F_C = F_X / e$

Where:

F_Y, F_Z .... required forces
M_X .... required torque moment
e .... perpendicular distance between F_X and F_Z forces
F_A, F_B, F_C .... actuators forces
h_A, h_C .... actuators piston position

The cross beam and the longitudinal beam (one end) are firmly fastened to the base. Two forces *(F_Y, F_Z)* and torque moment *(M_X)* take effects on the free end of longitudinal beam. The forces orientation is shown on the Fig. 10.

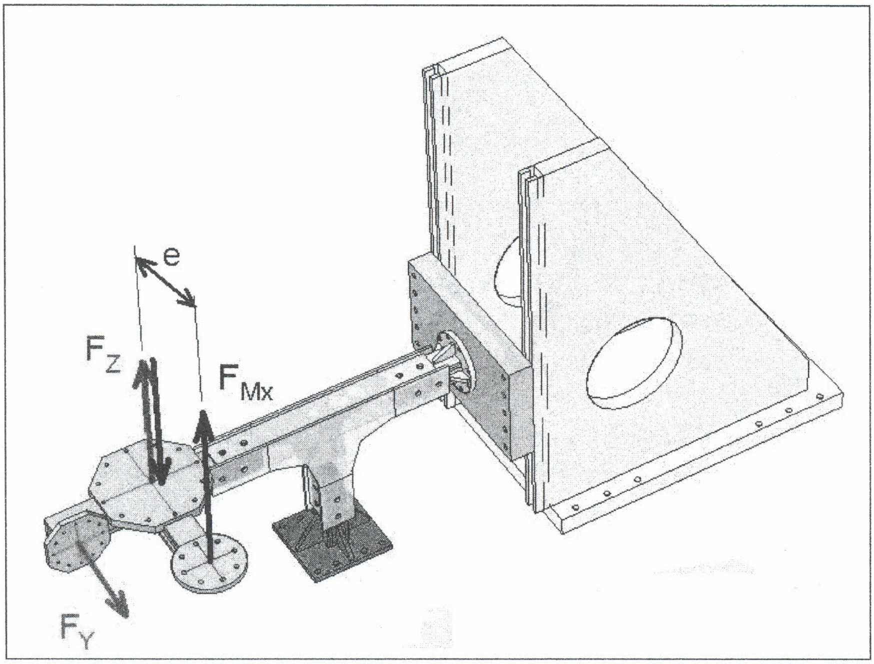

***Fig. 10** Forces orientation*

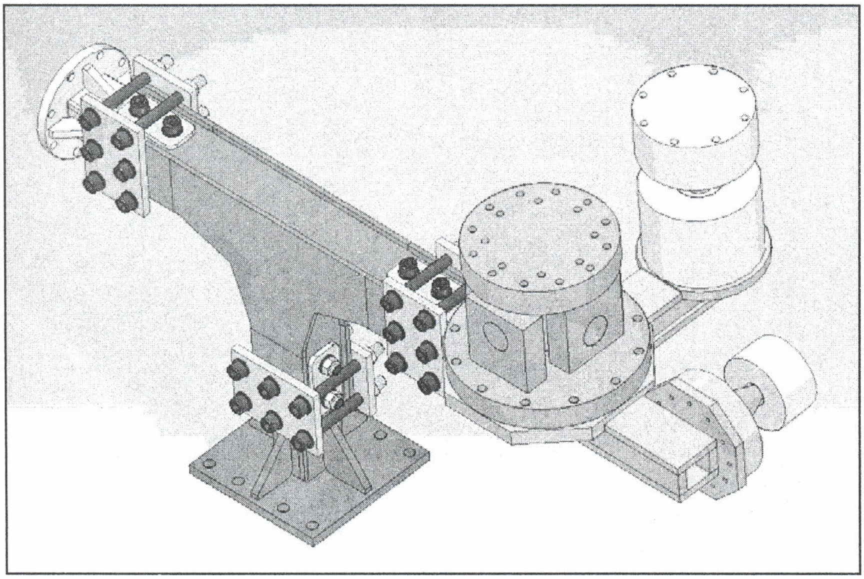

***Fig. 11** Detail of specimen fastening*

5. Submission uni-axial (UA) for multi-axial (MU) load

An example of the procedure of transformation (triple-cylinder MA test to double-cylinder test or single-cylinder test) is described in following points:

1. **Proposal of MA load parameters** - initial point for comparison. A simple harmonic signal without phase shifts (between each other actuators) was chosen for all load forces.
2. **Proposal of alternative load parameters** - variants for comparison multi-axial load. The aim of this step is to propose few variants with one or two active actuators against multi-axis load. These variants of load must be given by load response as multi-axis load.
3. **Verification by FEM** - very important step for evaluation of proposed variants. Using the FEM analysis results for correction of alternative load parameters increase the accuracy of achieved load response.
4. **Experimental tests** – verification of theoretical part. Experimental tests are provided in the laboratory (located in experimental base of Jan Perner Transport Faculty) on electro-hydraulic stand for dynamic and static tests. A lifetime of specimens will be compared against all variants of load.

6. Example

The result of the FEM analysis of one variant is follows described for illustration. The FEM result for multi-axial load (*Fz = 10 kN* and *Fy = 10 kN*) is shown on Fig. 12, against the result for one-axial load (*Fz = 10 kN*) on Fig. 13.

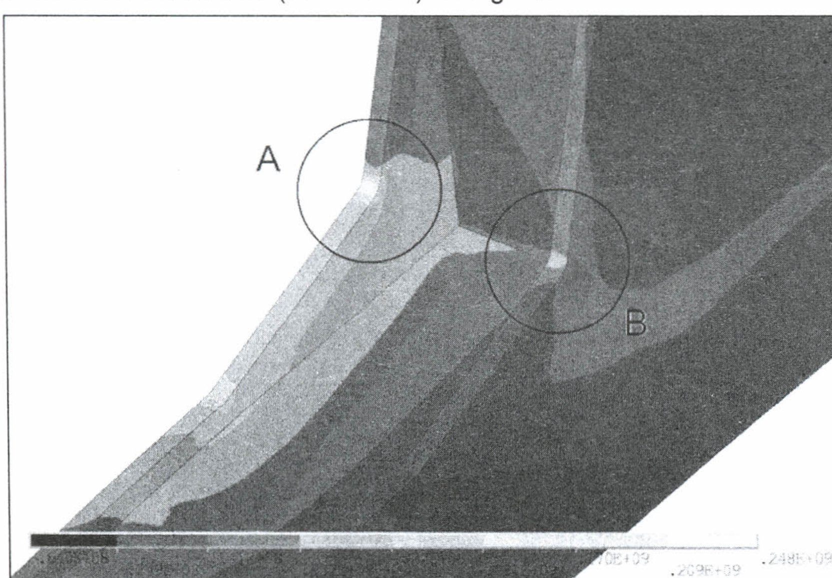

Fig. 12 *FEM analysis results for Fz = 10 kN and Fy = 10 kN* [2]

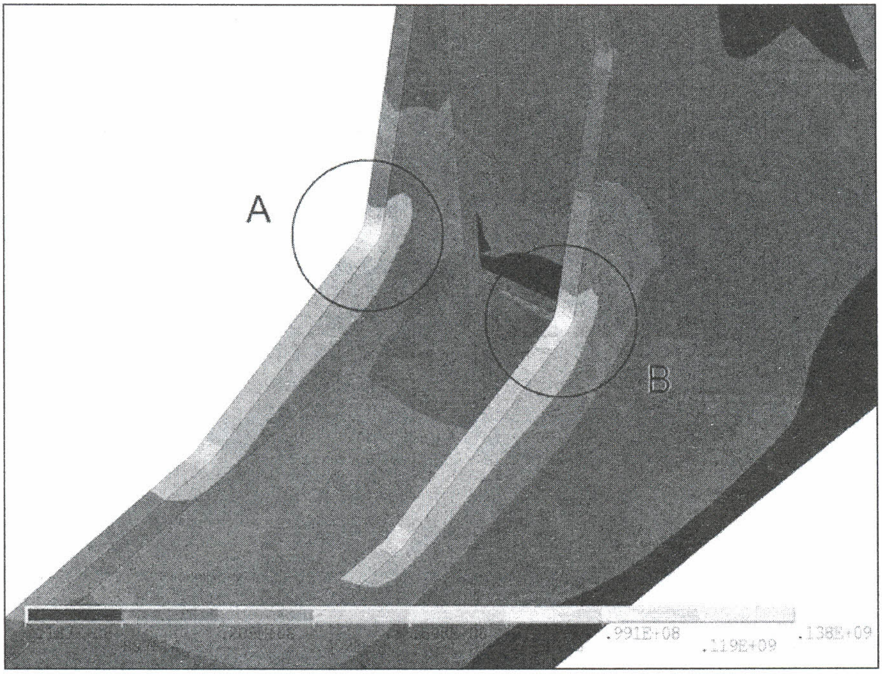

Fig. 13 FEM analysis results for Fz = 10 kN [2]

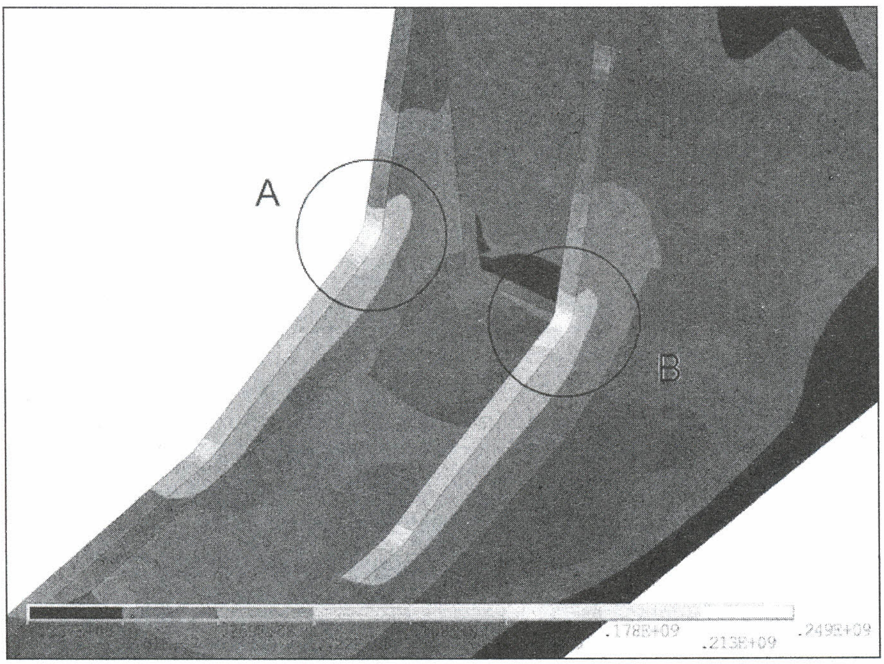

Fig. 14 FEM analysis results for Fz = 17 kN [2]

The value of mechanical stress (σ_1) in critical place **A** is *248 MPa* in first case and *138 MPa* in second case. The distribution of mechanical stresses in both cases is different. Achieving same values of mechanical stresses in the critical place **A** is possible by increasing of *Fz* force (Fig. 14). This increasing of *Fz* force has effect on mechanical stress in the critical place **B** (Fig. 14) also. Taking into account the fact that the specimen is symmetric, this change can be accepted. The final value of *Fz* force is *17 kN*. The result of FEM analysis for alternative load is shown on Fig. 14.

7. Conclusion

The proposal of alternative load parameters is based on theoretical (FEM) method. For this reason it is very important to verify these theoretical results by experimental tests. The alternative load can be designed in a different ways. Many variations of directions, values and point of application of alternative load forces can be used. It is possible that different solutions can probably find for one variant.

The system of load, results of FEM analysis and shape of critical place will be verified by first test. A confirmation or negation of all assumptions described in the paper will be done in the next research step and subsequent tests will be executed afterwards.

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Acknowledgment

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Literature

1. VÁGNER, J.,CULEK, B. ml,CULEK, B. *Simulace rozhodujících složek provozního namáhání částí kolejových vozidel na multiaxiálních zatěžovacích standech*, Přehledová zpráva VCKV č. B5-01-2008, Pardubice 2008
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Resumé

MOŽNOSTI ZJEDNODUŠENÍ MULTIAXIÁLNÍCH ZKOUŠEK RÁMŮ PODVOZKŮ ŽELEZNIČNÍCH VOZIDEL

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U experimentálního testování životnosti rámů podvozků železničních vozidel se obvykle používá multiaxiální zatížení. Testy na celých konstrukčních celcích jsou proto poměrně náročné na vybavení laboratoře, na přípravu a realizaci zkoušky. Všechny tyto faktory samozřejmě nepříznivě ovlivňují cenu zkoušky. Z tohoto důvodu je výhodnější testovat pouze nejvíce exponované konstrukční části. Celková životnost konstrukce se posuzuje podle velikosti mechanického napětí v několika nejvíce exponovaných místech. Cílem popisovaného experimentu je zjistit zda lze navrhnout úpravu v systému zatížení konstrukčního uzlu, která by vedla ke snížení počtu válců. V tomto konkrétním případě se jedná o nahrazení tříosé multiaxiální zkoušky konstrukčního uzlu dvouosou nebo dokonce jednoosou zkouškou. Hlavní podmínkou je, aby navržená změna v systému zatěžování vykazovala porovnatelné výsledky s původním systémem zatížení.

Tento příspěvek popisuje postup přípravy experimentu za použití MKP výpočtů. Je zde popsán výběr a návrh vzorku pro tento experiment. Dále je popsán systém řízení třech zatěžovacích válců. Jsou zde také prezentovány výsledky několika provedených MKP výpočtů, které umožnily optimalizovat kritickou oblast vzorku. Na závěr jsou prezentovány výsledky MKP výpočtu zjednodušení dvouválcové zkoušky na jednoválcovou zkoušku ukazující, že stejné hodnoty mechanického napětí lze v kritické oblasti vzorku dosáhnout i s menším počtem válců. Všechny tyto závěry budou ověřeny experimentem.

Summary

POSSIBILITY TO SIMPLIFY MULTIAXIAL TESTS OF RAIL VEHICLE BOGIE FRAMES

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The multi-axial loading is usualy used for experimental fatigue tests of rail vehicle bogie frames. These tests are expensive, time-consuming and depended on laboratory equipment afterwards. For this reason it is preferable to test only the most exposed parts of construction.

The aim of work was to determine possibility to find a solution for reduction of total number of actuators. In the paper was described specimen design process and its optimalization. In the next part was discussed procedure of transformation of triple-cylinder multi-axial test to double-cylinder test or single-cylinder test. Theoretical results will be verified by experimental tests.

Zusammenfassung

VEREINFACHUNGSMÖGLICHKEITEN VON MULTIAXIALENPRÜFUNGEN DER DREHGESTELLRAHMEN VON SCHINENFAHRZEUGEN

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Für die experimentelle Prüfung der Lebensdauer der Drehgestellrahmen von Schienenfahrzeugen wird in der Regel die multiaxiale Belastungsteste benutzt. Diese Prüfungen von gesamten Baueinheiten sind sehr anspruchsvoll auf die Laborausrüstung, die Vorbereitung und Durchführung. Aus diesem Grund werden Tests nur die am stärksten exponierten Teile der Struktur bevorzugen.

Das Ziel der Arbeit ist festzustellen der Möglichkeit zur Verringerung der Anzahl der Zylinder im Test. In diesem Artikel beschreibt man das Konzept und die Optimierung des Musters. In weiterem Teil beschreibt man das Beispiel der Transformation den Zweizylindertest auf dem Einzylindertest. Die beschriebenen theoretischen Ergebnisse werden mit dem Experiment verifizieren.