Stress analyses and optimization of bus chassis using software package CATIA and comparative methods

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1. Introduction

Damages do not take effect individually, but in mutual interaction. Fracture, which is a most severe form of material damage, is under influence of numerous factors, such as: stresses, temperature, atmospheric conditions, shapes and dimensions of a structural element or construction; mechanical properties of material and quality of surface [1, 2]. Considering the results, obtained by numerical simulation and strain gauges were performed with the redistribution of critical stresses, and proposal for the structure optimization. The vehicle which is under investigation is an articulated bus characterized by a length of 18 m, realised by the joining of two chassis (Figure 1), capable of carrying up to 130 passengers and with a mass at full load of about 25,000 kg. Urban buses, as most part of passenger vehicles, are built around a tubular chassis that bears both the weight of the vehicle itself and the weight of passengers and luggage [3, 4]. During the exploitation of articulated bus, there was a weakening of links between chassis and bus turntable after a while, a fracture of bolts that form the connection. Because it came to a frequent failure and accidents due to fracture of bolts, there had to be done a thorough analysis of the problems and to propose solutions of the design improvement, that was a problem with the whole series, not only one bus [3, 5]. Constructor of the bus suggested inserting a wedge that will take some of the load from the chassis link instead of bolts that are carrying the entire link. It was necessary to prove whether this is the optimal solution [4]. Avoid installation of wedges and testing of the buses, there should have been found an appropriate testing mechanism, therefore is FEM analysis software package CATIA selected and measuring the existing stress condition using the strain gauges [6].

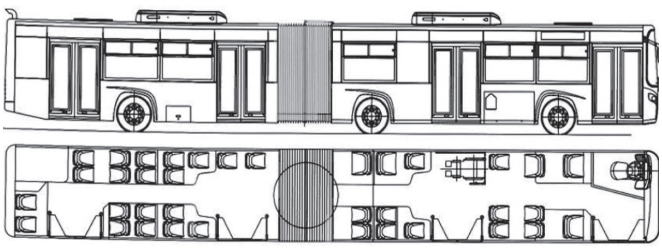

Figure 1. Model of articulated bus.

The most studies on this similar process have been rarely reported, while most research efforts have focused on the numerical analysis of bolt–nut connection [7], its failure analysis [8, 9], and the optimum shape design for improving the tightening force [9]. It is because the failure in the screw–nut connection, lead to the overall failure of the chassis.

2. Experimental part and discusion

The aim of this study is to determinate the strength of bolts which connected the front and back of the bus chassis. The experiment was done in several phases, which serve to give a complete state of stresses. This type of analysis gives a complete state in the construction of the bus as well as the critical locations of chassis connection with the turntable and the stress state of the bolts that make the connection.

The first phase: During this phase is done generation and production of CAD models through which a numerical simulation will be done in software package Catia, model is faithful to the original design. The modeling of the bus structure is made with data collected from producer of bus. In the first phase of the experiment initial numerical simulation was done with determined loads in order to locate critical areas of the construction and that would also be input for the second phase of the experiment. The analysis is limited to the chassis and turntable of the vehicle: it is fundamental to remember that when the bus during the drive is performing a cornering maneuvers because bad road, the centripetal acceleration force given by the contact between asphalt and tires together with the inertia forces acting on the body and on the connection with turntable. Also very important in the numerical simulation was included force of tightening the bolts which included very large initial stress in the connection of turntable. Loads acting on the bus during the driving are self-weight of bus, passenger weight, luggage, engine weight, fuel weight and extra tire weight. But the two main loading cases are bending load due to the weight and torsion stiffness due to the relative vertical movement of the wheels. In the first phase of the experiment initial numerical simulation was done with maximum allowed loads and was done not for the purpose of obtaining the values of stress but to visually determine the weakest region in the structure on which goal is to prepare places for bonding strain gauges. The Figure 2 presents the model of turntable and critical locations with maximum stress. The simulation shows that maximum stress is obtain in the steam of bolt.

In the second phase was done measuring of the stress using strain gauges which are positioned at critical locations of the construction that we have identified in the first phase.

Measuring of stress is performed using strain gages at 10 measuring points. Disposition of measuring points is shown in Figure 3 (in figure is shown only 8 measuring points). In order to compensate the effect of temperature on the accuracy of the measurements, each measuring tape associated with another compensation measuring tape in a semi-conductor.

Speed is measured by an optical encoder OMRON. From transmission ratio of the gear shaft which is derived vehicle speed. Accelerations were measured in the longitudinal, lateral and vertical directions using tri-axial sensor Silicon Designs 2460-010. Acceleration sensor is placed on the floor of the bus. All sensors and strain gauges are connected to two parallel connected measurement acquisition device SPIDER 8 productions HBM. Measurements have been made in the case of an empty bus mass 15,760 kg and loaded buses with sandbags to the total weight of 25,420 kg. Before the measuring on the polygon and in driving cases, were measured impact of tightening the screws with the specified torque of 400 Nm, and the change of the stress state at the measurement place.

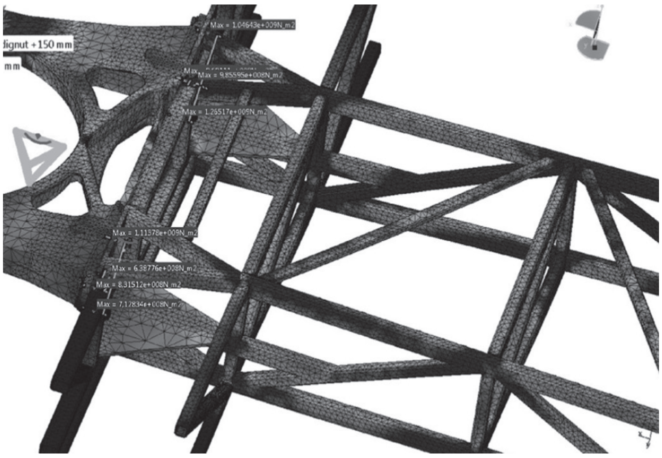

Figure 2. Connection of turntable with the chassis and areas of maximum stress.

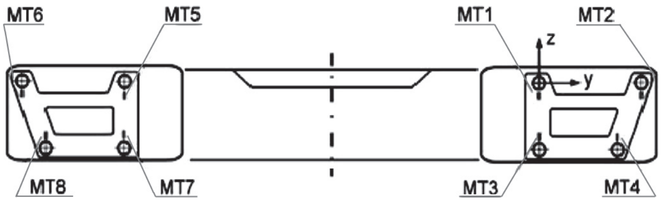

Figure 3. Position of measuring gages on the turntable

Measuring the impact of this torque was done while the bus was on the crane, and then is done release and then tightening of the screws one by one. Stress state of strain gages depend on dominantly tightening a screw near which the gauges is, the change of the stress state of each gage under the influence of proper torque nearest bolt is shown in Table 2. After the influence of torque test on the stress state in the area of bolts, measurements were carried out on the polygon. It is simulated the case of climbing and crossing the deformations on the road with a height of approximately 150 mm. Table 2 shows the results of measurements with an empty bus while climbing the left wheel of middle axle and the right wheel on the rear axle is on camber of 150 mm. Level controls left and right sides of the vehicle were independent from the two sensors. It may be noted that the stress shown on the diagram are not fully stabilized, but the gradient of further increase is very small.

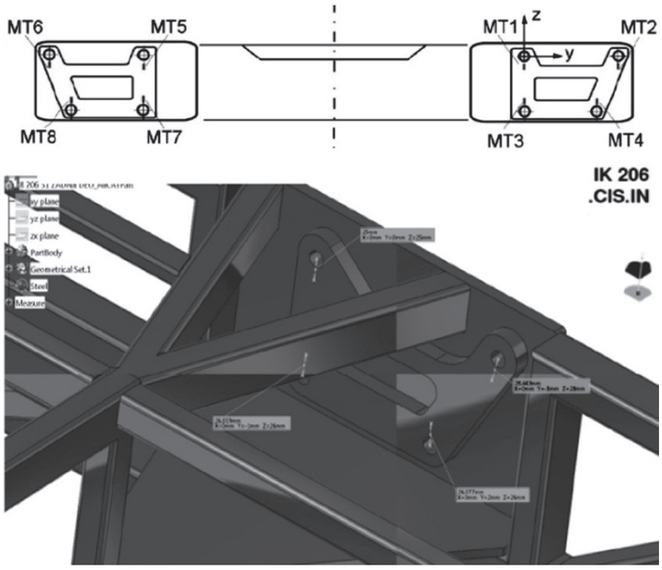

Figure 4. Measuring sensors in CATIA at the same palce as a strain gauges during the test.

Table 1 also presents the results of measurements during the transition from level control with two sensors to adjust the height of a single sensor. An empty bus was standing on the swells, so

Table 1. Measured Stress State of screws.

Measuring Tapes	Stress Δσ from tightening [N/mm^2]	Stress in case elevated left wheel in the central axle right wheel in rear axle - Empty bus – two sensors	Stress in case elevated left wheel in the central axle and right wheel in rear axle - Empty bus single sensor on right side
MT1	35.0	-14.1	-6.8
MT2	27.8	-0.6	-0.3
MT3	42.0	14.1	10.3
MT4	32.0	17.5	12.5
MT5	32.3	6.6	-1.0
MT6	44.8	10.7	6.4
MT7	52.0	-38.7	-9.0
MT8	44.9	-39.0	-9.7
MT9	17.2	-0.2	-2.2
MT10	8.1	1.0	-0.1

here was elevated left wheel in the central axle and right wheel in rear axle by about 150 mm. Strain gauges was not possible to measure the stress state in the steam of screws, but in place just above and below the screw.

In the third phase, is important to verify that the numerical simulation is authoritative for such complex analysis and whether it will give reliable results. All previous tests and simulations were carried out on bus chassis which was not modified, without wedges.

Repeated numerical simulation of chassis with loads was done, and those were identical, during simulated load measurements, that were at the test site Figure (5a) and (5b). The results have good matching- the difference is about 8-10%.

Figure 5a. climbing one wheel of the rear axis - test under controlled conditions.

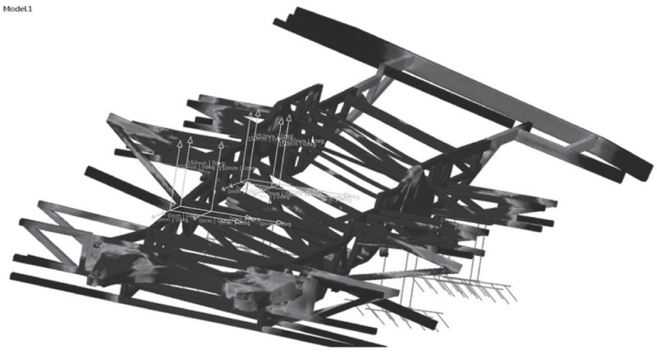

Figure 5b. Simulation of deformation of buses chassis simulated load.

The idea is to apply this method and determine stress state of bus chassis in a modified state when beside the bolts, and wedges receive load also. That is why in this phase is done numerical simulation under the same conditions and loads that were on the test polygon. So, in this section for comparison and validation of numerical simulation, set the sensors to measure the stress on the numerical simulation of the same places where were placed and the measuring tape.

The fourth phase FEM simulation of rising and lowering the rear left and right wheel of the bus here is presented. The simulation corresponds to the testing in with strain gauges; it is simulated that wheels of bus coming on the prepared obstacles. During the raising is performed the measurements. In the simulations were taken raising the supporting plate on the chassis for buses for the +150 mm and -150mm. In Figure 6(a). is shown, the analysis done for the turntable assembly with bolts to the original non modification state. Where is visible, that the shearing is dominant and uneven in the cross sections of the bolt.

Figure 6(a). Stress state in the screws connection of chassis, when the right rear wheel of bus come on obstacle +150 mm, case without the wedges, non-modification case.

Combined loads are visible and uneven distribution of stresses in the cross section of the screw. The main load are shearing and bending, and tension on bolt. In Figure 6(b). is shown, the stress analysis for the turntable assembly with bolts to the modified state with wedges. Where is visible, that the shearing was reduced to the minimum. In Table 2 is shown comparative overview of the stress value in screws, (Rising of right sides of bus +150mm) with wedges and without it.

Table 2. Comparative overview of the stress value in Screws, (when rising right and left sides) with widgets and without it.

Number of screws	Rising of right sides of bus +150mm		Rising of left sides of bus +150mm	
	Without wedges	With wedges	Without wedges	With wedges
	Stem of screw [N/m^2]	Stem of screw [N/m^2]	Stem of screw [N/m^2]	Stem of screw [N/m^2]
1	9.691e+008	1.032e+008	1.103e+009	1.123e+008
2	1.046e+009	1.014e+009	8.447e+008	9.172e+008
3	1.265e+009	1.262e+009	6.885e+008	5.994e+0082
4	9.856e+008	9.445e+008	7.425e+008	7.945e+008
5	1.114e+009	1.259e+009	7.711e+008	9.312e+008
6	8.315e+008	9.27e+008	1.056e+009	1.036e+009
7	6.388e+008	5.356e+008	1.445e+009	1.396e+009
8	7.128e+008	7.664e+008	9.465e+008	8.953e+008

The stress value decreased quite, for one order of magnitude, which shows, that the solution with the wedge is much better, because it reduces the screw load.

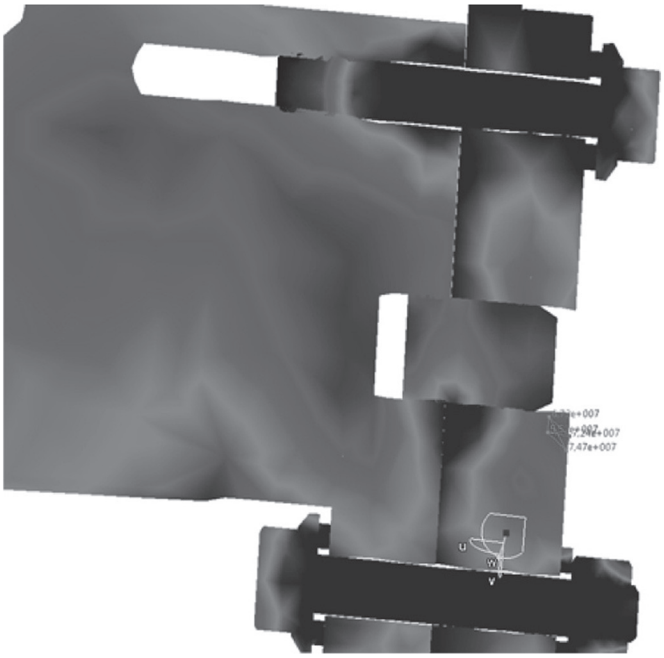

Figure 6(b). Stress state in the screws connection of chassis, when the right rear wheel of bus come on obstacle +150 mm, case with the wedges, modification case.

3. Conclusion

In this work are considered numerical and experimental analyses of stress distributions of the turntable of bus. Primary attention has been to verify structural analysis using FEM in system CATIA for redesign process of bus structural components. Experimentaly determined stresses using strain gauges, which are placed, as close as possible to the screw in order to measurement remains valid, above or below the screw connections. The measurement has been performed during test driving with empty and loaded bus. Strain gauges are placed relatively far from the area where the maximum stresses occur in the screw connection. The measured stresses are relatively high, indicating the occurrence of relatively high load of elements connection. Based on the conducted measurements can also be concluded that in terms of the load of screw connection of the turntable chassis it is better for the bus to have regulation of bus height with active sensor on the central axis. Measuring the stress caused by the bolt connections of torque of 400 Nm (specified by the manufacturer turntable) has been proven that the measured stresses corresponding simulated values of places in CATIA software package. FEM simulation was done for cases of lifting and lowering right and left rear wheel of the bus. Using numerical simulations it was found that the stress at the measuring points 1 and 5 (Figure 3) are several times higher than in the situation with wedges. Numerical simulations based on FEM, verified with experiments, can be used as efficient and reliable tool in redesign of the complex construction such as bus construction that is used in our investigation.

Acknowledgements

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