

The Strength of the Bus Structure with the Determination of Critical Points

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A monocoque structure of an airport bus is a very demanding product as regards its strength. With the application of the FEA (Finite Element Analysis) method the allegedly critical points of the framework were determined; these especially occurred on the door frameworks. The experimental methods of measuring mechanical deformations confirmed the presumptions that maximum deformations measured at the points which were previously analysed with the FEA method. The driving regime with a maximum speed of 40 km/h in a circle with a minimum turning radius and a changeable regime of acceleration and braking proved critical. The measurements led to appropriate construction amendments, additional strengthening of the framework and other measures which fulfilled the required strength criteria.

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0 INTRODUCTION

The framework of a bus is a self-bearing construction made from steel profiles welded together in a monocoque.

The monocoque consists of a chassis frame and the frameworks of the front and rear panels, the left and the right panels, the roof, the dash board and other components.

The chassis and the body are one and the same structure.

The self-bearing monocoque bus construction means that it is completely prepared for the installation and fitting of the bus chassis and the body systems and sets.

The monocoque construction predetermines the places where the engine, the transmission gear, the suspension, the axles, the steering system and the other equipment will be fitted. A sufficient rigidity of the construction ensures elastic deformations of the bus framework, but keeps them within the maximum permissible limits so that they do not affect the functions of individual aggregates and systems.

Above all this refers to the door function; their opening and closing, a limited deformation of the air-conditioning device mounted on the roof, and the unaffected function of the propulsion installations, the engine etc. There should be a favourable ratio between the rigidity and the weight of the bus which also serves as a criterion for proving and estimating the

successfulness of the construction in reference to its carrying capacity and own weight [1].

A special feature of the airport bus regarding the wheelbase of dimension 8400 mm was taken into account. Therefore specific and especially extreme loads were included in the project and construction analyses. The strength analysis provides a comparison with the data on similar buses which in the past suffered from the occurrence of cracks, roof waving, deflections of the tracks, cracks on the door corners etc.

1 THE BASIC STRUCTURE

A monocoque consists of four modules:

- a) the chassis frame,
- b) the left and right panel frameworks,
- c) the front and rear panel frameworks,
- d) the roof.

The basic part of the monocoque is the chassis frame onto which the panels and the roof are mounted. The positioning of the main points for the installation of the systems and aggregates is controlled vertically with regard to the floor, laterally with regard to the centre of the axles and longitudinally with regard to the determined distances.

The roof framework is the final part of the monocoque and is positioned according to the positions of the side and other panels in relation to the chassis frame. This stage of the technological process is followed by adhering the

metal sheets to the monocoque structure which provides the latter with reinforcement and at the same time solves the issues of noise and temperature isolation, vibrations, uneven surfaces etc.

2 A MONOCOQUE, THE SELF-BEARING BUS CONSTRUCTION

Monocoque is the self-bearing construction for fitting of the propulsion system of the vehicle: the engine, the clutch, the transmission gears, the suspension, the axles and individual sets of the braking, steering and other systems.

Due to this function, the monocoque is an essential part of the bus as it has to be designed in a way which enables an uninterrupted and simple fitting of all the systems and aggregates to their pre-determined installation positions. The self-bearing monocoque construction is a step forward and represents a pre-defined form, design and function. In addition, all analyses of the crash impact tests are taken into account.

3 THE APPLICATION OF THE FEA METHOD

A linear modular analysis FEA is used to determine the basis for the analysis and testing of the strength with an experimental method. The objective is determination or a rough estimation of the load and deformations of the monocoque.

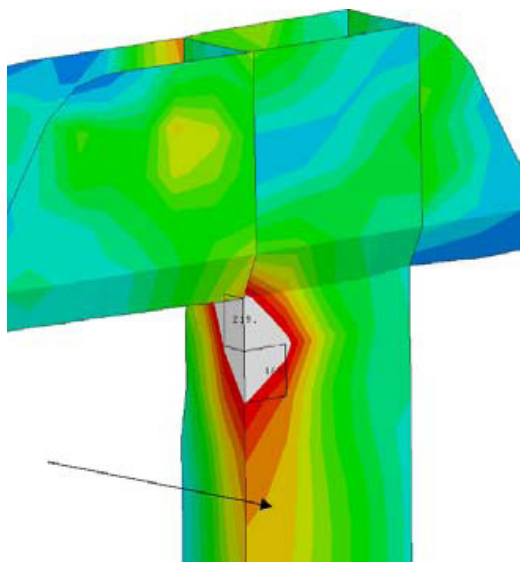


Fig. 1. FEA with a local concentration of tension

More specific data are only obtained experimentally using the strain gauge, i.e. by applying the method of measuring the strength with electrical resistance. The FEA model only served to determine the locations where the measuring tapes will be applied (Fig. 1).

On the most loaded locations 32 points were determined at which measuring tapes were adhered to the framework at an early stage of the monocoque construction. In this phase the starting values of deformations and strength were determined which had a »zero value« in the finished bus – the system was re-set and the bus's own deformations were neutralised after the installation of the bus equipment; so in measurements only absolute values were taken into account.

Combinations of measuring tapes (Fig. 2) which registered deformations in all directions, i.e. in x, y, z orientations, were used. These were linear measuring tapes and rosettes which are normally used in measuring composed loads and deformations.



Fig. 2. Adherence of the measuring tapes

4 PREPARATION OF THE CONSTRUCTION FOR MEASUREMENT

The self-bearing bus construction was tested using the measuring tapes on 32 locations (Fig. 3) which were determined after a preliminary analysis and a FEA calculation. The most critical points were the corners of the six bus doors which was also indicated by the tension measurement [2].

The bus in the monocoque form was tested statically and dynamically. The testing was carried out for different cases of the framework

loading, i.e. for different regimes of driving of an unloaded and loaded vehicle. The following analyses were made [3]:

- analysis of the vehicle's statics,
- analysis of acceleration and driving ahead,
- analysis of braking,
- analysis of driving in a circle with acceleration and braking.

The maximum permissible tension with regard to the used material and the manner of use of the bus was 150 MPa.

An example of the tension calculation is given according to the equation Eq (1).

$$\sigma = E \cdot \varepsilon = 2.1 \cdot 10^5 \cdot 850 = 178.5 \text{ N/mm}^2 \text{ (MPa)}. \quad (1)$$

Table 1 presents partial results of the measurements of the bus structure strength for the different driving conditions.

5 THE METHODOLOGY OF MEASUREMENTS AND MARGIN CONDITIONS

Maximum tension values were achieved at the measuring points during the driving of a loaded bus in a circle with braking. The test surface on which the experiment was carried out was uneven with holes and bumps. The tension oscillations were especially emphasised due to the impact loads at passing through obstacles [4] and [5]. We arrived to the following conclusions:

- a) The testing, i.e. measuring of the propulsion strength of the bus framework was carried out under special conditions which are not suitable for the regular use of the bus. The driving regime of a fully loaded bus with sharp braking in a bend presented a critical test of the strength.

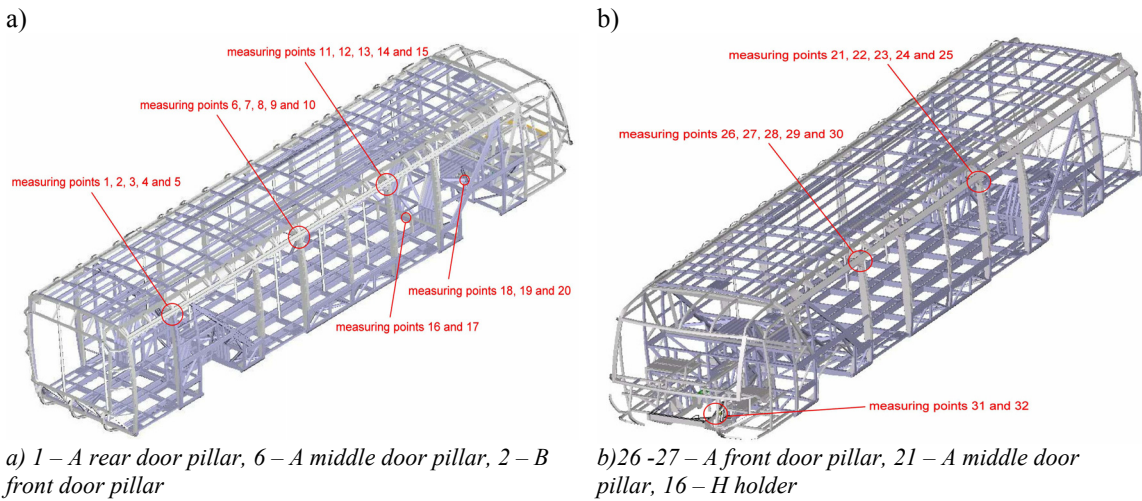


Fig. 3. Measuring points: a) on the left, b) right side of the framework

Table 1. Maximum deformation values ($\mu\text{m/m}$)

Point	Driving regime	1	6	12	16	21	26	27
01	unloaded – on the spot without zero adjustment	155	-600	25	140	-670	90	-60
03	unloaded - driving	15,5	-37	-20	5	-	11	7
07	unloaded – driving – bend + breaking	120	180	295	310	-	110	160
08	loaded	-70	340	30	5	320	-90	130
10	loaded – driving + braking	-300	620	70	380	530	-260	330
12	loaded – bend + braking	320	660	-400	380	850	-280	440
13	loaded – on the spot – elevated at the back	1075	350	-360	-140	400	-185	250
14	loaded – driving – without H-holder	-695	625	-200	250	570	-200	360
15	loaded – driving + braking – without H holder	-710	700	-340	275	610	-200	490

- b) In the case of an unloaded bus the deformations and tensions at point 16 (65.1 MPa) and at point 12 (61.95 MPa), both under 150 MPa which is supposed to be the maximum permissible value of the strength of the framework material.
- c) The design relating to the propulsion strength derives from the loading conditions which were determined according to the following criteria:
 - 70% driving on the airport:
 - 40% acceleration and driving,
 - 30% normal braking (extreme braking 2 to 5%),
 - 30% driving in a circle;
 - 30% waiting – staying at standstill.

6 THE MEASURES FOR INCREASING THE RESISTANCE MODULUS IN THE LONGITUDINAL DIRECTION

Regardless of the test results the following measures for increasing the resistance modulus in the longitudinal direction were taken [6]:

- strengthening of individual parts of the existing construction: the track, the door pillars, the roof etc.,

- new solutions on the framework of the second prototype which included additional joints in the framework,
- other measures – modifications of the framework.

All critical points which were determined on the basis of FEA were constructionally analysed and appropriately strengthened. Figs. 4 to 7 show deformations of the critical points on the framework and in the area of the opening for the middle bus door [7]. The measuring points 6 to 10 determined deformations on the left side of the middle door; the measuring points 21 to 25 determined deformations on the right side of the middle door in the case of a fully loaded bus. Position 6 was a linear strain gauge on the lower part of the horizontal profile near the front pillar of the right middle door. Position 7 was a linear measuring tape on the rear side of the front pillar of the right middle door near the upper horizontal profile. The measuring points 8, 9 and 10 were joined in one strain gauge – a rosette, where two of the three measuring tapes were adhered at 90° angle (horizontal and vertical network) and the third measuring tape was adhered at 45° angle [8] to [9]. The rosette was located in the middle of the front strengthening plate to the right of the middle door [10].

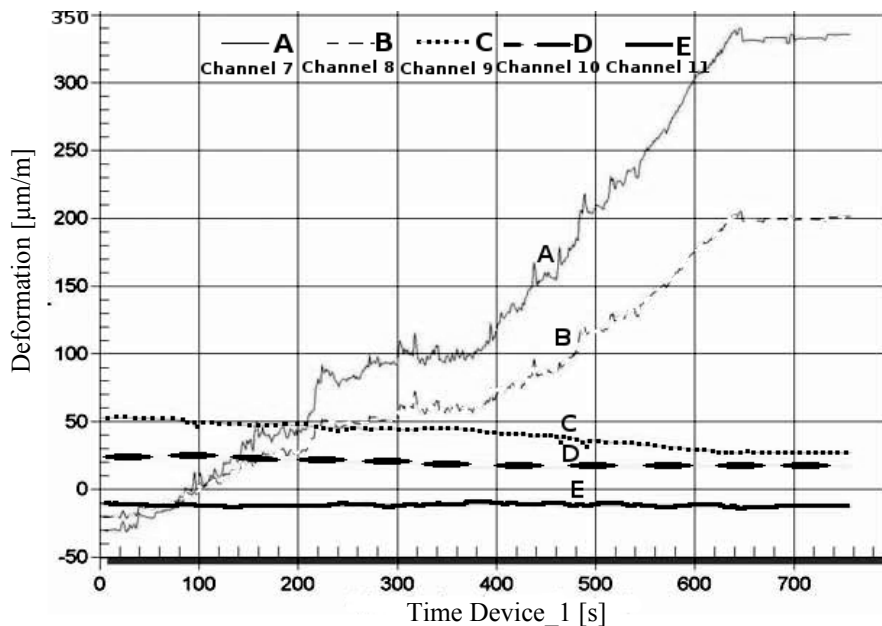


Fig. 4. Strains at measuring point 6 to 10 of a loaded vehicle

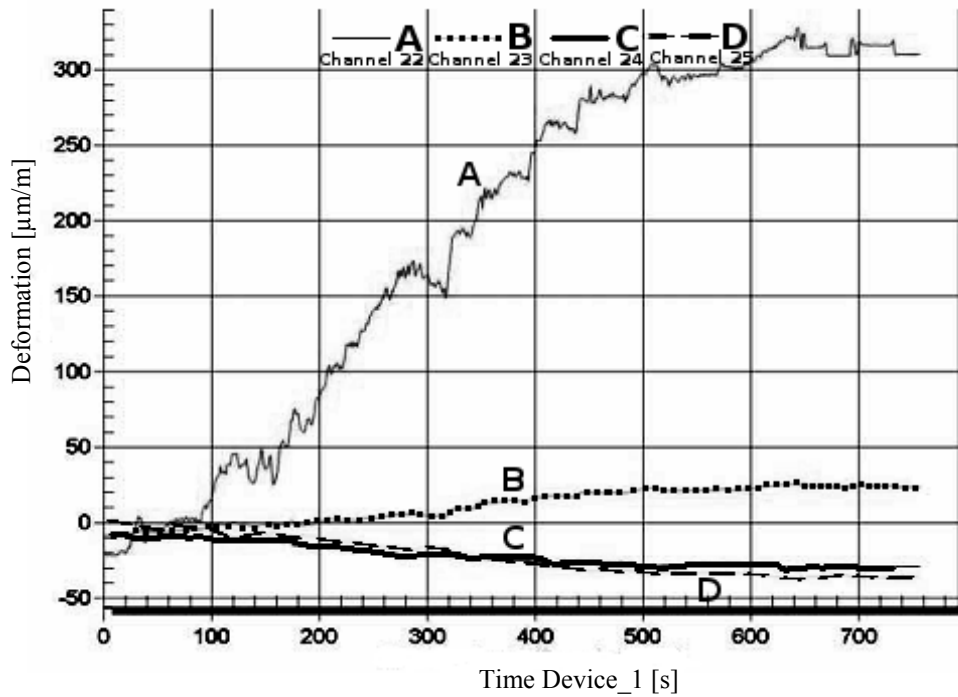


Fig. 5. Strains at measuring point 21 to 25 of a loaded vehicle

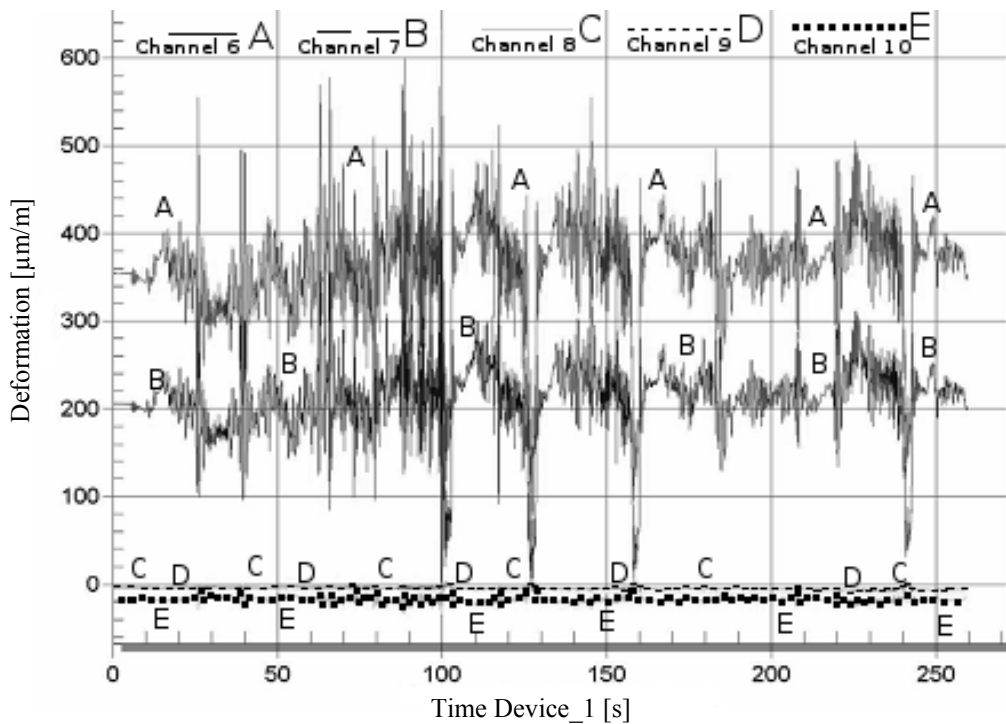


Fig. 6. Dilatation at measuring point 6 to 10 during the driving and braking of a loaded vehicle

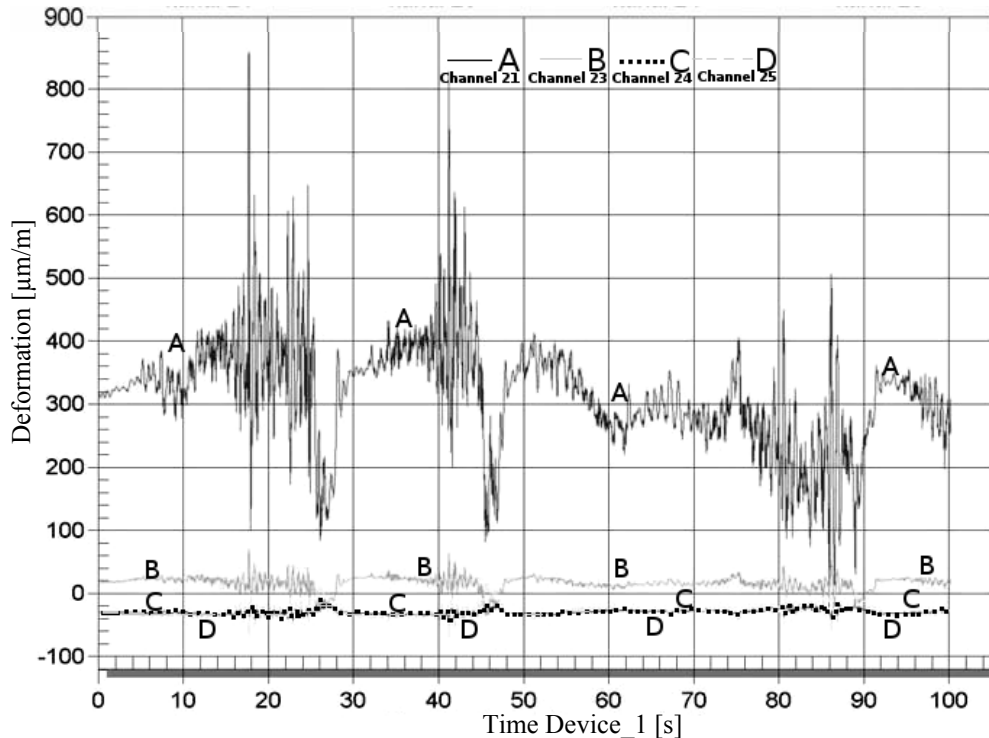


Fig. 7. Strains at measuring point 21 to 25 during the driving and braking of a loaded vehicle

The location of the measuring tapes on the right side of the framework followed the same principle as on the left side which is shown in Fig. 3. The deformations of the framework at critical points did not exceed $350 \mu\text{m/m}$ at static loading [11] and achieved maximum $800 \mu\text{m/m}$ during the driving of a loaded bus [12] and [13,14].

7 CONCLUSION

The experimental methods of measuring mechanical deformations confirmed the presumptions that maximum deformations were measured at the points which were previously analysed with the FEA method. The driving regime with a maximum speed of 40 km/h in a circle with a minimum turning radius and a changeable regime of acceleration and braking proved critical. The measurements led to appropriate construction amendments, additional strengthening of the framework and other measures which fulfilled the required strength criteria.

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