BOX MODIFICATION OF EMU SERIES
EN 57– COACH RA

Robert Owsiński¹a, Grzegorz Misiura¹b

¹Department of Mechanics and Machines Design, Opole University of Technology
ar.owsinski@doktorant.po.edu.pl, bg.misiura@doktorant.po.edu.pl

Summary
This paper presents the box modification of EMU series EN 57 after retrofit. The aim of this modification was to observe the national law described in the regulation of the Minister of Transport and Water Management concerning the signature of railway stock. This modification is required to adhere to the durability and construction standards (PN-EN 12663:2010E), as well as to the UIC 505-1 standard. On the basis of calculations, it can be concluded that the level of stress generated in the EMU roof structure under the specified compressive load does not exceed the limit values. The results of the analysis of the strength of the isolated model of side displays showing the installation of EMU type EN57 indicate that the analysed design solution provides sufficient strength to transfer the load requirements in accordance with the PN-EN 12663-1:2010E standard.

Keywords: vibrations, electrostatic precipitators, finite element method

1. INTRODUCTION

Electric multiple units of the EN57 series are the basic traction unit used to carry local traffic and inter-provincial trains in Poland.

The EN57 series designated as 5B-6B-5B is a developed form of the EW55 series designed to handle agglomeration traffic. The manufacturing of EN57 dates back to 1961. The vehicle was produced until 1993 in PAFAWAG factories located in Wrocław in three main series. As indicated by the marking, the vehicle is equipped to handle both low and high platforms. It is composed of three separate coaches: control (Ra, Rb) are rolling coaches, while the middle (S) is a driven coach with the traction motors placed in a bogie frame. The individual units are connected by a semi-rigid coupling (ZEK), also called a factory-coupler. These are couplers which cannot be disconnected when the electric multiple unit is running, as well as during the operation period. Individual electric multiple units (EMUs) are
joined by an automatic coupling invented by Scharfenberg. This allows coupling and decoupling of up to three EMUs during their operation period in multiple control mode, provided that the connected vehicles are of the same type or are compatible.

The steel construction of the individual coach body consists of the following main units:

- mainstay
- side walls
- end walls (back and front)
- the roof.

The mainstay of the coach is made of rolled profiles, pressed and bent sheet metal. These are the main components of the longitudinal beams (stringers) and transverse (crossbeams) - the whole structure is welded. Places that are the most sensitive to vibration and tension, i.e. headstocks and torsion beams (beams, where spigot are mounted), are manufactured as spigot-joined structures [1,2].

Side walls, front walls and the roof are manufactured as a welded construction with bent profiles and rolled profiles. The profiles are manufactured ribs with longitudinal and transverse beams which form an internal skeleton covered with sheet metal with an addition of copper. The columns of the side walls are based on a horizontal top shelf with a side sill. In the case of body coach Ra except a modification allowing the building the information boards had to be carried out a modification of the forehead construction of the front wall by building a completely new design of the front wall. This must meet the requirements imposed on crash rail vehicles. In addition, the front wall structure is adapted for mounting by the method of a bonding face made of reinforced polyester with glass fibres. [1,2].

The mainstay, roof and walls provide a unified, self-supporting structure, which ensures the high strength and stiffness of the construction.

Shunting carriages are based on two rolling bogies upgraded to the 45AN standard – axle pattern 2’2’ with a spacing of 2700 mm. These bogies have tyred wheel-sets inconsistent with the requirements of TSI, hydraulic dampers, springs packages beams, rubber-metal springs which replaced the suspended coil spring as the first degree of dampening. The distance between the bogie for coach Ra is 14900 mm [1,2].

The construction of the body provides a transfer of compressive loads in the axis of the coupling at a value of 1500 kN. The mounting equipment within the body meets the requirements of UIC 566 [3] and PN-EN 12663:2010 [4].

Due to the out-dated design solutions and the fact that these vehicles do not meet the standards [4], operators have decided to modernise this series. Retrofitting requires structural changes and redesigning of the interior in order to make the vehicle comply with the existing requirements.

In 2012, the company “Tabor Szynowy” Opole S.A., which is one of the rolling stock repair works plants in Poland, won a tender for major repair with modernisation of 21 EMUs of the EN57 series. The repair was to be performed for the operator – PKP SKM Trójmiasto Sp. z o.o. Nowadays, the process of major repair with modernisation is completed only on one vehicle.

During the process of major repair with modernisation, many changes have been implemented in order to improve the traction characteristics of the unit (EMU). What is more, modification of the components of the box was carried out to adapt the vehicle to current regulations. It became necessary to equip the unit with external information boards in the curvature of the roof, so that the vehicle fulfilled the requirements [5] specified in the Regulation of the Minister of Transport, Construction and Maritime from the 3 January 2013. The Regulation describes the method of keeping the register as well as the label method of the rolling stocks and other rail vehicles.

2. DESCRIPTION OF ROOF MODERNISATION

The guidelines for major repair and modernisation were included in the Terms of Reference (Specific Essential Conditions Orders) provided by the contracting authority. They pointed out the necessity of building information boards in the curvature of the roof of all the coaches. The process had to be in compliance with applicable national and railway regulations. It was necessary to meet the conditions [5] specified in PN-EN 12663-1:2010 [4] Railway application – Structural requirements of railway vehicle bodies as well as the requirements for the gauge in accordance with the international railway regulations presented in UIC 505-1 [6].

The Terms of Reference require that information boards are built in the central section of the coach. It turned out to be impossible to build them according to this requirement in Ra and Rb coaches, because it would collide with a toilet built in the Ra coach (lack of access to the information board) and required the undercut of two roof frames. This would unnecessarily weaken the structure of the box by calling the effect of stress concentration which results from the scheme load-supported beam at two points. The final location where information boards were built is shown in Figure 1.
The electric multiple unit during operation works in a complex state of tension. Therefore, the display building construction was based on the steel grade S355JR due to the fulfilment of the criteria analysed in the preparation of the design. These criteria are divided into the following categories:

- **General:** relative cost, weight (mass) included.
- **Mechanical:** elastic modulus, strength, durability, fatigue index included.
- **Heat:** consisting of thermal conductivity, diffusivity, melting point, solar impact resistance, creep resistance and others.
- **Wear:** indicator of wear.
- **Corrosion:** rate of corrosiveness.

Only after a complete analysis of the above criteria, it was possible to correct the design stage. Please note that there is one important factor on which it was based, i.e. the designer’s experience and intuition.

With the use of CAD (Computer Aided Design) / CAM (Computer Aided Manufacturing) systems, it was possible to optimise the design, which significantly reduced the cost of its implementation. Optimisation of the body structure had a positive impact on reducing the weight of the vehicle. This was an important factor, as the weight of the vehicle after major repair with modernisation could not exceed the weight of the vehicle before repair with retrofit. Furthermore, the proper choice of materials used during the major repair process increasingly eliminate even subjective errors. The selected materials have the best application and technological properties: they allow for reduction of weight and cost of materials and products made of them.

At the design stage, several options were considered for building the information boards in the electric multiple unit coaches. At the same time, an unsuccessful attempt was made to obtain the consent of the customer (SKM Trójmiasto Sp. z o.o.) to transfer the information boards to the beltline. Such a modification would not significantly affect the strength properties of the coach body. Therefore, in order to check whether roof modification would not significantly lower the strength and fatigue properties of the electric multiple unit body, numerical calculations were performed to verify two limit states:

- capacity of showing that the values of the internal forces of external loads are less than the carrying capacity element
- use of showing that the deflection element and other displacements are smaller than the limit values [7]

In order to obtain meaningful results, it was decided to calculate both vehicle models: introduced before the modernisation and after the retrofit process. The comparison of the results of the analysis revealed that the modification would not significantly affect the strength of the coach body.

Before starting major repair with modernisation of the vehicle, it was completely demolished. Only the mainstay with the body was left untouched. At the first stage, the structure was cleaned during a sandblasting operation both inside and outside. At the second stage, it was protected against corrosion. At the third stage, the coach was set on a specially prepared area of repair and was given deflection. Only after the granting of deflection was it possible to start all the necessary works related to the modification of the box or front of the coach.

Due to the size of the LED array designed for installation, it became necessary to undercut the frame section (profile Z) to the height of 295 mm from the longitudinal beam of the side wall and then strengthen the area with the profile Z welded to the frames adjacent to the cut (cf. Figure 2). The aim was to cause the transfer of the load to the frame of the neighbouring undercut and additional strengthening of the structure in the location that the modifications were carried out.

![Fig. 2. Undercutting and strengthening of frames](image)
housing of the display made of steel grade S355JR are summarised in Table 1.

Table 1. Mechanical properties at ambient temperature of flat and long products of steel grades of quality groups, for which a value of labour violations by PN-EN 10025:2007 [8]

<table>
<thead>
<tr>
<th>Material</th>
<th>$R_{el}$ N/mm²</th>
<th>$R_m$ N/mm²</th>
<th>A %</th>
</tr>
</thead>
<tbody>
<tr>
<td>S355JR</td>
<td>355</td>
<td>470 – 630</td>
<td>&lt; 3, $L_o = 80\text{mm}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≥ 3, $L_o = 5.65 \sqrt{S_o}$</td>
</tr>
</tbody>
</table>

Where: $R_{el}$ - upper yield strength, $R_m$ - tensile strength, A – constriction.

The housing is welded into the roof structure. It is embedded on the longitudinal beam of the side wall above the window, supported from the top on the transverse profile (Z-profile) and roof structure (the frames, the longitudinal beams and plating). Welding was carried out under the supervision of the Department of Technology and Product Development and the Chief Welding Engineer. It was required to meet the CP B class of weld quality according to PN-EN 15085 [9]. The manufacturer’s certification level was determined as CL 1 according to PN-EN 15085 [9]. The developed documentation of welding technology ensures the conduct of the process, which allows for achieving the lowest possible shrinkage stress and strain smallest welding. The adopted welding technology provides the required documentation quality of welds and adherence to dimensional tolerances. Welding was done via the 135 (MAG) method.

Once the welding works were completed, the Quality Control Department of the company received the works. For the first performed piece, it provides non-destructive testing using a method of penetration with the use of a powder and, if possible, with the use of the ultrasonic method. Furthermore, after major repair of the body, a leak-test was carried out: the vehicle body was wetted. The result of the test was positive, as there was no water inside the coach body.

The next part of this paper presents calculations made by using the finite element method in order to check the effect of modifications on the strength of the Ra coach body.

3. NUMERICAL CALCULATIONS

Carrying out numerical calculations for a real electric model traction unit in order to determine the stress distribution, as a result of application of standard load values, is practically impossible. The complexity of the design of a single coach is huge. The design of the box is made up of more than three thousand components (Fig. 3 Fig. 4).

For the purpose of the work undertaken, it was decided to simplify the calculation model and perform numerical calculations for a representative fragment of the shell. To this end, identical roofing fragments based on a simplified spatial model of the coach (Fig. 5) were chosen.

In accordance with the requirements specifically defined in the above standard, the following exceptional loads for the P-II vehicle category were considered:

- compressive load of 300 kN applied to the waist level of the roof,
• compressive load of 300 kN applied to the window sill waist level,
• compressive load of 400 kN applied at a height of 150 mm above the floor plane of the vehicle.

The calculation model takes into account all the elements having an impact on the operation of the coach. It also determines the appropriate boundary conditions of numerical analysis. The geometrical dimensions and shapes of various elements adopted under developed in Tabor Szynowy Opole SA took into account the modernised design documentation of the vehicle. The modification was done with the use of materials compatible with the requirements of PN-EN 10025:2005 [8].

The remaining supporting structure of the roof section of the car has not been changed. It is not necessary to consider its impact on the size of the stresses in the zone which has been modified. Therefore, the numerical calculation is carried out only for the first illustrated variant, which provides a compressive load on the roof of the wagon to be applied. Two specific load cases were examined.

Static roof analysis

The previously mentioned complexity of the actual design of the coach makes it practically impossible to carry out a proper analysis of the static state of the normalised load. Therefore, it was decided to appropriately convert and adapt an analysed 3D model into a form which provides the correct solution using the Finite Element Method (FEM). To obtain accurate results, the elements which are the most optimal solution for thin-walled structures were used in the calculation model surface. The number of finite elements needed to perform the analysis is significantly reduced. Static analysis was carried out for two variants: 1 - base structure before modification; 2 - modified structure.

The numerical calculations were carried out using a representative model of a partial fragment of the coach including the roofing and box structure of the display. For this purpose, a 2000 mm fragment of the vehicle roof was selected. In the first case, we assess the roof before modification; in the second case, we assess the roof after strengthening the construction with a built-modified side of the display box structure (Fig. 6, Fig. 7).

Retrofitting the EN 57 unit with side displays required the technological treatments described above. Such an effect on the supporting structure requires additional studies to identify potential stress concentration and to verify whether the modernised construction meets the standards of the railway.

For a representative element of plating, two static analyses were performed with the use of the Finite Element Method (FEM). The first one-sided load on the present assumed geometry and restrained it at the opposite end. Another analysis assumed the degrees of freedom deprivation on the sides of the element and the application of a uniform compressive load on the opposite ends perpendicular to the axis of the coach. Both cases comply with the requirements described in the standards for testing loads.

Analyses indicate that a representative model section of the roof before and after structural changes shows no significant differences in stress level reduction. The reduced stress maps are illustrated in Fig. 8 and Fig. 9, respectively, for the model before and after modification. Stress distribution and their values in the case of the first type of loading are similar to each other. The second load case showed convergent stress distribution, but different stress values at the point of concentration.

In both cases, the maximum stress values occurred in the profiles of reinforcement in the area of application of the load. Such a phenomenon in the current design does not emerge, because the location of load application is
the location of the intersection of the virtual model. This fact should be taken into account in the analysis of the results.

Fig. 8. Von Mises stress distribution on base model – Load variant 1

Fig. 9. Von Mises stress distribution on modified model – Load variant 1

The distribution of the displacements caused by the so-defined load profile indicates that the display box structure also stiffens the support structure in this area of the coach (cf. Fig. 10 and Fig. 11). The values of displacement at maximum load are insignificant and convergent in both cases: before and after the modification.

Fig. 10. Displacements on base model – Load variant 1

Fig. 11. Displacements on modified model – Load variant 1

The second load case simulates a bilateral compression model. According to Fig. 12 and Fig. 13, differences in the maximum values result from the change in load distribution on the two components of opposite directions. Therefore, in this case, the effect of stress concentration on the basic model was approximately reduced by half of the maximum load obtained when using the first variant.

Fig. 12. Von Mises stress distribution on base model – Load variant 2

Fig. 13. Von Mises stress distribution on modified model – Load variant 2

Separation of the loading force resulted in a reduction of the displacement value relative to the first variant. The distribution of displacements confirms the high stiffness of the display box.

Fig. 14. Displacements on base model – Load variant 2

Fig. 15. Displacements on modified model – Load variant 2
4. CONCLUSIONS

Implementation work on the boxes ensures the fulfilment of the requirements specified in the design documentation and the Technical Conditions Execution and Acceptance developed for the complete vehicle body to the modernisation of the electric multiple units for the SKM EN57 series Trójmiasto. Carrying out welding work does not give rise to undesirable stresses in the modified structure: the technology of welding work minimises the risk of introducing large amounts of heat in areas which have a decisive influence on the strength of the box.

The introduced modification consists in the building of side information boards allowing the vehicle to reach the current standards and regulations concerning the labelling of railway vehicles with the requirements relating to the strength of the box and the gauge. The housing of the display was designed to provide convenient access to an array of information from the inside of the vehicle. The construction itself does not interfere with the elements of the vehicle.

Numerical analysis with the use of the Finite Element Method for the two load cases showed that the modification of the roof of the EN 57 couch does not have a negative impact on the strength of the superstructure. The values of reduced stresses obtained in the analysis are evenly distributed, and they do not exceed the limits.

The demonstrated locations of stress concentration in the model does not actually cause a stress concentration of such values. This is due to a number of simplifications of the actual structure in order to convert it into a computational model. It was necessary to use surface elements to perform FEM numerical calculations, because the model was based on thin-walled components.

The proposed box structure fully meets the intentions of the design. Well carries the load support structure stiffness weakened and does not introduce additional stress concentration locations.

References

3. UIC 566 Loadings of coach bodies and their components
4. PN-EN 12663-1:2010 Railway application – Structural requirements of railway vehicle bodies.
5. Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 3 stycznia 2013 r. w sprawie sposobu prowadzenia rejestru oraz sposobu oznakowania pojazdów kolejowych.
6. UIC 505-1 Railway transport stock – Rolling stock construction gauge.