NUMERICAL ANALYSIS OF METRO DOOR COMPONENT TRANSMITTING LOADS TO BASIC STRUCTURE

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Abstract. The authors have introduced an original design of a metro door in previous outputs of the ongoing research. The designed door will be used on a real vehicle of the operated Prague metro M1. A type drawing of a reference vehicle has been introduced as well in compliance of operational requirements within the STN EN 14752 and STN EN 12663 standards. A detailed description of the operational principle of the mechanism has been published. On its basis, the kinematics of the door itself takes place. The program of the calculation of a parametric model of the force acting on the basic structure has been created. That model serves for sufficiently accurate and prompt quantification of forces generating in the door attachment, when geometrical and force parameters are changed. The creation of the model has led from an application of the free body diagram method to creation of calculation schemes and to subsequent setting up the equations of motion. From this work, the most unfavourable conditions of the acting forces to the hanging door system and their subsequent transmitting to the basic structure. These results are used in the presented contribution for numerical dimensioning of the metro door components, which transmit the loads to the basic structure. Numerical simulations are performed by the finite element method software Ansys in order to meet the normative safety requirements of the design. Based on the reached results, it is possible to conclude that the ultimate strength condition is fulfilled within the sufficient safety rate defined in the STN EN 12663 standard. It was obtained that the optimization of the analysed components could by performed in term of the weight, i.e. in term of the production costs. Considering the lifetime of the hinge and its quantity of the production, the presented state is applicable in the real operation.

Keywords: metro door, finite element method, railway vehicle.

Introduction

With the development of industry in cities and towns as well as due to the growing migration of large populations, it was necessary to introduce a system of adequate public transport [1]. It was connected with the efforts to develop as suitable type of a transport mean as possible. It should meet all requirements for this system of city transport [2; 3]. The city transport has undergone similarly to other fields a complex development from horsepower through steam engines to electric traction. The demand for passenger transport is not evenly distributed. This feature focuses in cities, suburban areas and city links. Both road and rail public transport have found a place in urban transport due to the undeniable benefits they bring [4; 5].

Fig. 1. **Prague Metro M1 with sliding type doors [6]**

However, the economic factor plays a major role in the design of the rail system, which is closely linked to the quantity of rail transport efficiency. The efficiency of rail transport can be expressed as the ratio of transport performance and costs for a given rail system. Rail transport is characterized by low variable, but high fixed costs, and, therefore, it is efficient only when it is properly loaded. It follows, that in places with high transport requirements, such as large cities and suburban areas, it is appropriate, even to the point of necessity, to introduce a suitable type of rail transport. One of them is the metro system (Figure 1), which represents the imaginary highest level of urban rail transport, and which uses its own infrastructure and track, often separated in height from other traffic [7-9]. For obvious reasons, the metro system can only be considered efficient in cities with a population of over one million. In principle, the track can be built in three ways, namely through underground tunnels, elevated flyovers, or on the ground surface. In practice, there are systems, that are operated exclusively by one or by the combination of these types of lines [7; 10].

This transport, also known as metro, subway, or underground, is a type of high-capacity public transport generally found in urban areas. In terms of terminology, the term metro is the most commonly used term for the subway in non-English-speaking European countries. Expressways can be named after various infrastructural features such as tunnels – the origin of the name subway, underground, Untergrundbahn (U-Bahn) in Germany or Tunnelbana (T-Bana) in Sweden. The use of viaducts or flyovers was an inspiration for names such as skytrain, elevated, overground or overheaded system. Some of these terms can be applied to the whole system, although a substantial part of the network, for example in remote suburbs, is at the level of road transport (surface line). Unlike buses and trams, an express track or a metro track is an electrified railway line, which operates exclusively on a separate track body (track surface), which is inaccessible to pedestrians or other vehicles of other types and which is often separated in height, underground tunnels or elevated structures above the ground level. In English, this is called Right-of-way (transportation). Metro operation is safe, convenient, independent of street events [4; 7; 11].

Materials and methods

The design of the technical solution of the metro door (Figure 2) was presented in the work [12]. The doors are of the sliding type with an electric drive and a power transmission by means of a screw and guide nuts. Table 1 provides a summary of the geometric and weight parameters of the proposed door system.

Fig. 2. **3D model of the designed door system**

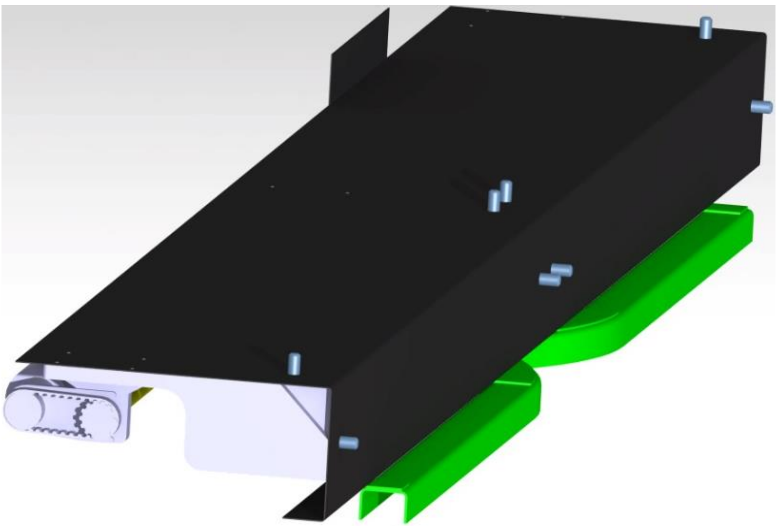

Fig. 3. P**osition of screw joints for mounting the door mechanism to the coarse structure (an upper part)**

As it can be seen in Figure 3, for the mounting the mechanism in the upper part of the door, eight screws are used. Four screws are oriented horizontally and four vertically. Other eight screws are placed on door wing edges – four right, four left. Two screws are used for attachment of a holding arm (Figure 4) and other tow screws are used for attachment of the arm of the lower door guidance (Figure 5). Totally, the door system is attached to the coarse structure by sixteen screws M10.

Both arms are shown in Figure 4 and Figure 5, and they are the object of the FE analysis presented in this contribution.

The holding arm is not mounted fixed to the door. It is attached to the coarse structure, and it serves to restrain the vertical movement of the door in the axis direction.

Table 1

Door parameters

Parameter	Value	Unit
Maximal door width	1 856	mm
Maximal door height	2 190	mm
Height of the door wing	2 077	mm
Width of the door wing	781	mm
Weight of the door wing	50	kg
Weight of the door mechanism	80	kg
Total weight of the door system	180	kg

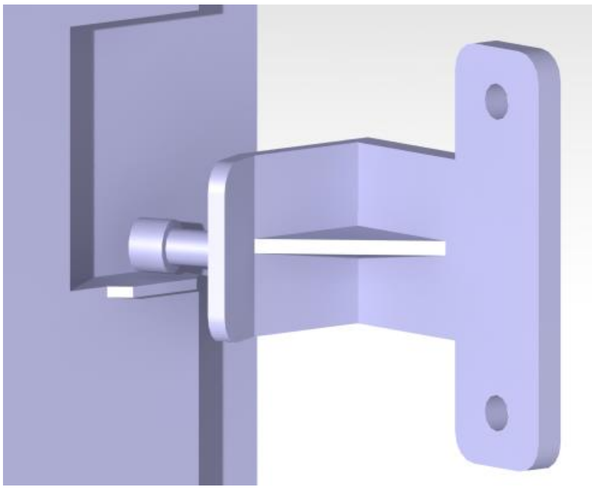

Fig. 4. **3D model of the holding arm**

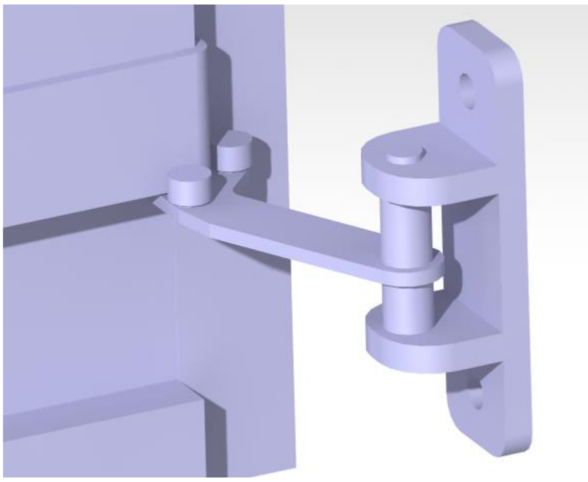

Fig. 5. **3D model of the lower guidance**

In principle, it ensures the door in the lower guidance. The holding arm (Figure 4) is located on the sides of both door wings. The lower guidance (Figure 5) allows both to guide and to support the door during opening and closing movement. Moreover, it holds the door in the closed position and prevents movement in the *x* and *y* axis directions (movement in the metro length direction and movement of the sliding motion of the door). For this model, a parametric analytical model for determining of the loads in the door fixing points on the coarse structure is presented in [12-14]. The finite element analysis is performed to investigate the distribution and values of stresses and deformations by means of the finite element method [15-17]. After a thorough analysis of the issue, it was determined that the holding arm and the hinge on the lower guiding will be analyzed. The forces, by which the elements are loaded in simulations, were calculated using the parametric model and they are taken directly from the work [14].

The material used for the production of the analyzed components was determined as structural carbon steel with the designation EN S235J2. The yield strength of the material is R_e = 235 MPa, at which, the Poisson constant μ = 0.266 as well as the Young modulus $E = 2.1 \cdot 10^6$ MPa were considered. The simplifications used in the calculation consisted in simplification of the geometry of the analyzed components. Moreover, the screw joints were replaced by a fixing support (Figure 6). This modification has a negligible effect to the most loaded components.

To perform correct analyses, suitable element sizes of the FE mesh have to be chosen. This FE mesh created the geometry of the analyzed components as faithfully as possible. The same settings of the FE mesh were used for both analyzed bodies:

- OCTREE Tetrahedron with intermediate nodes.
- Type of the element: Linear.
- Size of the elements: 2 mm (Figure 7).

The applied forces correspond to the results provided by the compiled parametric model. Thus, the model is ready for calculation and verification of the designed functional geometry of the components used both to attach the subway door to the coarse structure and also with the required kinematic capabilities of the mechanism.

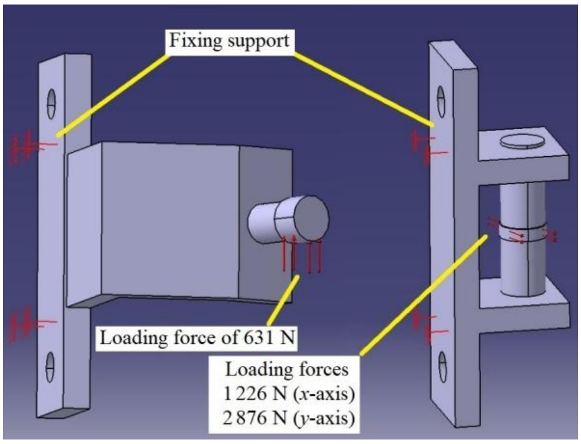

Fig. 6. **Boundary conditions defined for the FE analysis**

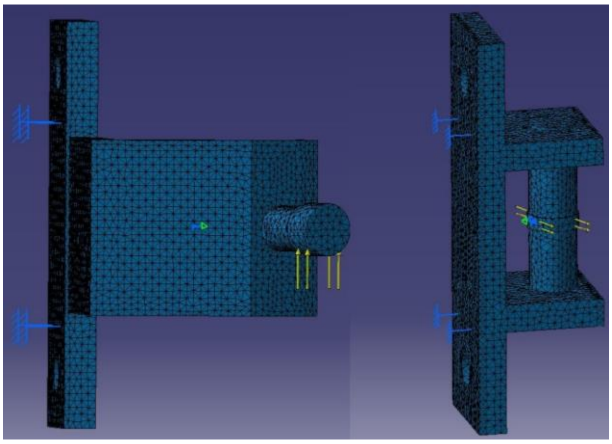

Fig. 7. **FE mesh for the FE analysis**

Results and discussion

Two types of results were selected, and they are shown in this section. The first set of the results is the maximum stresses, and the second set was the maximum deflection, or displacement of the solved structural unit. The distribution of the resulting stresses in the holding arm structure is shown in detail in Figure 8. These stresses were calculated by means of the von Misses hypothesis. Figure 8 shows the location with the quantified global maximal stress of 59 MPa. The calculated safety coefficient is regarding to the yield strength of 3.98.

The resulting stresses in the hinge of the lower guidance are shown in Figure 9.

These stresses are also calculated by means of the von Misses hypothesis. Figure 9 shows the location of the global maximum of 68 MPa. The safety coefficient for this component is 3.46.

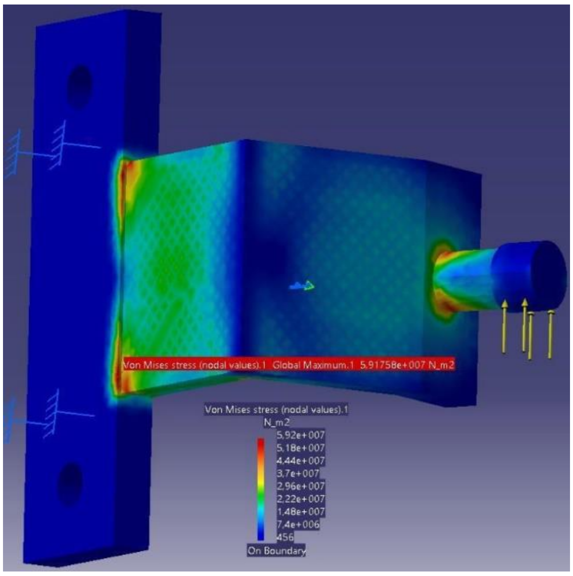

Fig. 8. D**istribution of von Misses stresses in the holding arm**

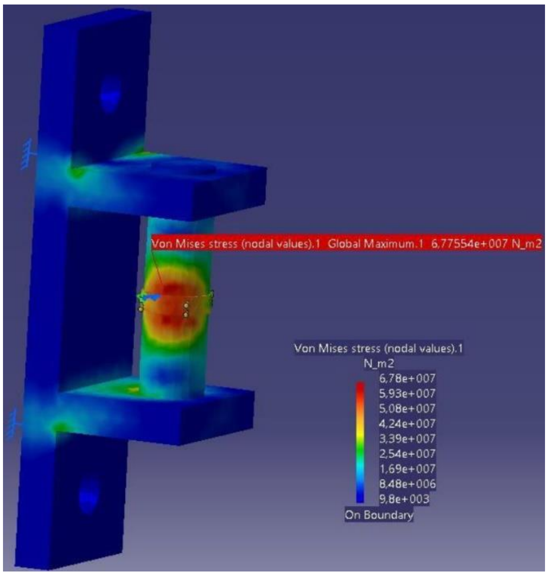

Fig. 9. D**istribution of von Misses stresses in the lower guidance**

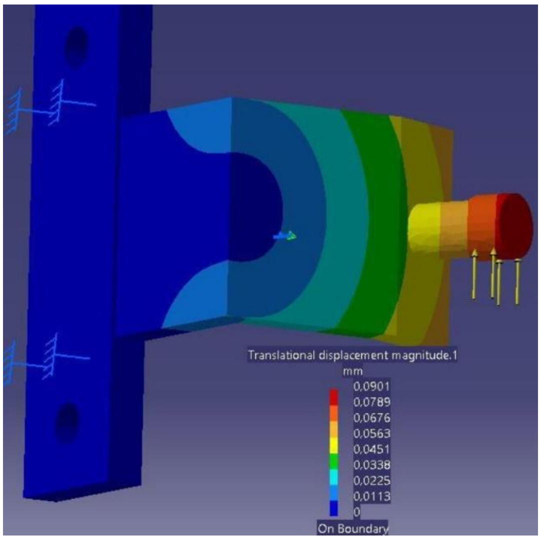

Fig. 10. D**isplacement of the node elements in the holding arm**

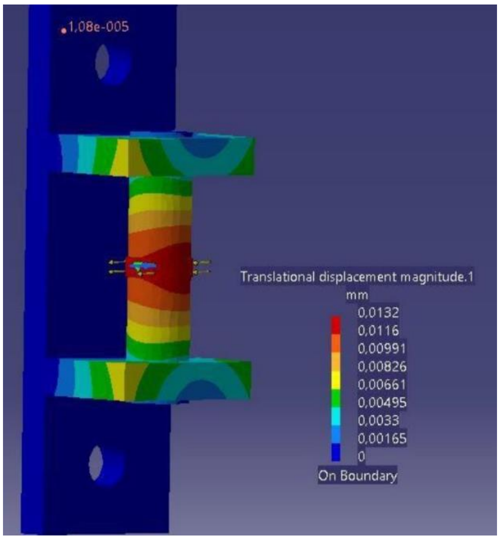

Fig. 11. D**isplacement of the node elements in the lower guidance**

The deflection caused by the most unfavourable load of the holding arm is shown in Figure 10. As it can be seen, the maximal value of this deflection is 0.09 mm. Figure 11 depicts the deflection of the lower guidance due to the most unfavourable load. Its maximal value in the denoted location is 0.0132 mm.

When the hinge of the lower guidance is loaded by the maximal forces of 1226 N in the x-axis direction and of 2786 N in the *y*-axis direction [12; 14], the maximal stress is 67 MPa. It meets the strength condition with the safety coefficient 3.46 for the yield of strength (235 MPa) of the used steel. The maximal deflection of the hinge is negligible 0.0132 mm in the location, where the forces act. Hence, it can be supposed, that it is acceptable. Based on these results, it can be concluded, that the strength condition is fulfilled for both load cases, in addition with a sufficient safety ratio. The maximal loads have been calculated based on the normative requirements prescribed in the STN EN 12663 standard and in the STN EN 14752 standard [18; 19].

Conclusions

1. Results of the research and simulations have shown that the analysed components are able to transmit the required and given loads.
2. In the load of the holding arm cases the stresses are within the safety coefficient and it is safely under the yield of strength of the used material. These results are acceptable from both the functionality point of view and the reliability of the entire door system.
3. It is obvious that the components are over dimensioned, and they could be optimized in order to reduce their weight. However, it is necessary to take into consideration the long-term reliability, lifetime of the system as well as production and assembly conditions.
4. The designed technical solution of the metro door and the entire mechanism are ready to be implemented on a real vehicle.

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Author contributions

Conceptualization, M.B. and J.D.; methodology, M.B. and A.K.; software, M.B.; validation, M.B and J.D.; formal analysis, M.B. and A.K.; investigation, M.B. and J.D.; data curation, M.B. and A.K.; writing – original draft preparation, M.B. and J.D.; writing – review and editing, A.K.; visualization, M.B. and J.D.; project administration, M.B. and J.D.; funding acquisition, J.D. All authors have read and agreed to the published version of the manuscript.

References

[1] Janak M. A model of force effect of a metro door vehicle on a basic structure. Thesis 2017. University of Zilina. (In Slovak).
[2] Rybicka I., Stopka O., Ľupták V., Chovancová M., Droździel, P. Application of the methodology related to the emission standard to specific railway line in comparison with parallel road transport: A case study. MATEC Web of Conferences, vol. 244, 2018.
[3] Kendra M., Babin M., Barta, D. Changes of the infrastructure and operation parameters of a railway line and their impact to the track capacity and the volume of transported goods. Procedia Social and Behavioral Sciences, vol. 48, 2012, pp. 743-752.
[4] Heller P., Dostal J. Rail vehilces III (In Czech). Plzeň: University of West Bohemia, 2011. 224 p.
[5] Dvořák Z., Leitner B., Novák L. Software Support for Railway Traffic Simulation under Restricted Conditions of the Rail Section. Procedia Engineering, vol. 134, 2016, pp. 245-255.
[6] Metro "Prague Public Transit Company". [online] [20.01.2022]. Available at: https://www.dpp.cz/en/company/about-the-company/company-profile.
[7] Melnik R., Koziak S., Sowiński B., Chudzikiewicz A. Reliability analysis of metro vehicles operating in Poland. Transportation Research Procedia, vol. 40, 2019, pp. 808-814.
[8] Mikhailov E., Semenov S., Tkachenko V., Sapronova S. Reduction of kinematic resistance to movement of the railway vehicles. MATEC Web of Conferences, vol. 235, 2018.
[9] Hauser V., Nozhenko O., Kravchenko K., Loulova M., Gerlici J., Lack T. Proposal of a steering mechanism for tram bogie with three axle boxes. Procedia Engineering, vol. 192, 2017, pp. 289-294.
[10] Harušinec J., Suchánek A., Loulová M., Strážovec P. Design of a device to simulate environmental influences on the course of brake tests. MATEC Web of Conferences, vol. 157, 2018.
[11] Kletska O., Falendysh A., Vasylenko O., Onyshchenko A. Definition of the coefficient of blackness for inhomogeneous surfaces under conducting thermography. MATEC Web of Conferences, vol. 178, 2018.
[12] Kurcik P., Blatnicky M., Dizo J., Pavlik A., Harusinec J. Design of a technical solution for a metro door system. Proceedings of the 13th International Scientific Conference on Sustainable, Modern and Safe Transport "TRANSCOM 2019", May 29-31, 2019, High Tatras, Novy Smokovec, Slovak Republic, pp. 767-773.
[13] Blatnicky M., Dizo J. Parametrization of effect of metro wagon basic structure door force model. Proceedings of the 20th International Scientific Conference "Engineering for Rural Development", May 26-28, 2021, Jelgava, Latvia, pp. 542-550.
[14] Blatnicky M., Dizo J., Barta D., Drozdziel P. Design of a metro door system and determination of main loads. Scientific Journal of Silesian University of Technology: Series Transport, vol. 105, 2019, pp. 49-64.
[15] Štastniak P., Kurčík P., Pavlík A. Design of a new railway wagon for intermodal transport with the adaptable loading platform. MATEC Web of Conferences, vol. 235, 2018.
[16] Fomin O., Lovska A., Kudelya V., Smyrnova I. Determining the dynamic loading and strength of the bearing structure of a covered wagon when firing from it. Eastern-European Journal of Enterprise Technologies, vol. 4, 2020, pp. 33-41.
[17] Gerlici J., Sakhno V., Yefymenko A., Verbitskii V., Kravchenko A., Kravchenko K. The stability analysis of two-wheeled vehicle model. MATEC Web of Conferences, vol. 157, 2018.
[18] STN EN 12663-1 + A1 standard "Railway applications. Structural requirements of railway vehicle bodies. Part 1: Locomotives and passenger rolling stock (and alternative method for freight wagons)."
[19] STN EN 14752 standard "Railway applications – Bodyside entrance systems for rolling stock."