ACTA TECHNICA JAURINENSIS
Vol. 17, No. 2, pp. 65-74, 2024
10.14513/actatechjaur.00729

Research Article

Analysis of Normative Requirements and Technical Specifications of a Structural Design of the Mechanical Device Operating in the Amusement Industry

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Submitted: 21/12/2023 *Accepted: 01/03/2024* *Published online: 14/03/2024*

Abstract: In current hectic times, people should be able to slow down and diversify their free time. Therefore, the contribution of the amusement industry should not be negligible but, on the contrary, should be seen as something where whole families can seek respite from ordinary worries and problems. For this reason, the presented paper was written, which represents an intermediate step in the design of an amusement facility suitable for amusement parks that respects the normative requirements. Technical standardization represents a set of rules, characterizations, guidelines, and results of activities necessary for mutual understanding when solving technical problems in production. Adherence to standards is essential when launching a product on the market. The main standard indicating the full functioning of an amusement device is STN EN 13814. Its analysis and the resulting technical specifications of the proposed equipment are the chief objectives of the paper.

Keywords: Amusement ride; Design; CAD (Computer-Aided Design) model; Standards; Specifications

I. INTRODUCTION

The object of standard STN EN 13814-1 and ISO 17842-1 standard is to specify the minimum requirements necessary to ensure the safe design, calculation, manufacture, assembly, maintenance, operation, inspections, and testing of mobile, temporary or permanently installed machinery and structures such as roundabouts, swings, flat rides, Ferris wheels, roller coasters and other amusement handling machines [1,2]. The mentioned devices must be intended for repeated installation without damage to the features or loss of integrity in temporarily or permanently operated amusement parks, funfairs, and any other places suitable for use.

The basic design rule is the safety of the occupants. Thus, the permissible gravity accelerations resulting from the standard must be considered at first [3,4]. The standard STN EN 13814 prescribes that the acceleration due to gravity acting on passengers must not exceed 6g. The reference point for the calculated and measured accelerations is 60 cm above the seat level. The maximum deceleration must not exceed 0.7g for emergency brakes and 0.5g for normal stopping brakes. The dimensions of seats and gondolas are designed with regard to the forces from self-weight, adverse loads and motion.

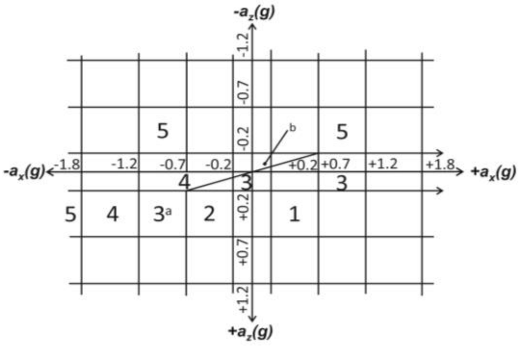

Figure 1. *Areas of application of restraint devices [3]*

As stated in STN EN 13814, all seats of amusement rides must be equipped with the necessary spine supports at least 0.4 m high. Moreover, the seat surface must have an appropriate slope towards the spine support. For the sake of the safety of passengers, seats fixed next to each other on the gondola should be designed in order that the minimum seat outline distance is 0.5 m. A safety factor of $\gamma = 6$ (-) is required in the dimensioning and designing of the seats [2,4]. On the basis of the acceleration acting on the occupants, we can design suitable restraint devices to ensure sufficient restraint and safety in the course of the ride (**Fig. 1**). Minimum requirements:

- Area 1 – no restraint devices are required;
- Area 2 – restraint for two or more passengers, manual device, optional backup, with non-adjustable restraint position;
- Area 3 – restraint for two or more occupants, manual restraint manipulated by operator or attendant, individually with adjustable restraint position;
- Area 4 – individual device for each passenger, automatically restrained in the operating position, individually with adjustable restraint position;
- Area 5 – individual device for each passenger, automatic restraining in operating position with check of restraint, unlocking by means of central system, with warning signal (light or sound), functional restraining required [2,16].

Motorized restraint devices can create additional hazards. Therefore, their movement must be sufficiently decelerated, and the maximum force measured at the edge of contact of the device must not exceed 150 N. Before restraint is initiated, electrically controlled restraint devices are equipped with a safety light system or an audible safety system to warn that the restraint is fully operational; thus, riding can commence [13-15;17].

II. PROPOSED AMUSEMENT RIDE

The authors decided to develop the amusement device with a changeable tilt of raising (arm raises horizontal platform) during rotation (**Fig. 2**).

Figure 2. *Proposed amusement device with changeable tilt in the course of lifting*

Passengers are seated in gondolas that are fixed to a steel structure. The wheel is spun through an electric motor, which is mounted on top of the main beam. The motor spins the structure by means of a gear train, where a pinion is the driving member and a large gear wheel attached to the structure mounting is the driven member. The entire structure is erected by means of hydraulic system and a 90˚ change in the position of the device is achieved. The process of lifting occurs only at a condition where the wheel reaches a maximum rotational speed of 14 rpm. The passengers experience a maximum gravitational acceleration of approximately 2.2g. The achieved wheel rotational speed ensures that the gondolas can be deflected by up to 53˚ after reaching the maximum speed before lifting begins.

Passengers must be secured with a restraining device in the course of riding, inasmuch as during lifting can occur a state when passengers going upside down. Due to the fact that the attraction is fully demountable, the operator is able to transport it between amusement parks or between smaller festivals where the amusement equipment is present. The mentioned amusement ride can be classified as a classic family amusement ride [9-12].

The primary assumption when designing the model of this handling device was that the wheel should rotate clockwise with a speed of n_k = 14 rpm. Analytical calculations are performed with regard to the maximum weight from passengers m_{Pmax} = 3600 kg. In terms of determining other specifications, it was necessary to choose for what number of passengers the attraction will be designed, and the required components that are essential for the proper operation and safe functioning of the attraction [5-7]. The other selected units will be designed using analytical calculations or software [18,19]. The chief specifications describing the equipment are divided into three groups:

1. Specifications intended for passengers;
2. Specifications intended for the operator;
3. Special specifications.

Passenger specifications should be displayed at each amusement ride on an information board for the reason that passengers can familiarise themselves with the type of operation or ride parameters before riding [6,14]. The selected parameters are:

- the number of passengers that the attraction carries in one ride – n_p = 36 (-);
- rotational speed of the wheel – n_k = 14 rpm;
- period of acceleration – t_r = 17 s;
- time of lifting to vertical position – t_z = 30 s;
- time of a ride – t_j = 2 min;
- age or height restrictions (persons must be older than 8 years and taller than 135 cm, restrictions must be met simultaneously);
- electric passenger restraint with additional manual restraint.

In addition to the above specifications, we specify additional specifications that must be known by the operator for proper care of the attraction, installation or dismantling:

1. number of gondolas – n_g = 18 (-);
2. number of trusses (truss construction) – n_l = 18 (-);
3. motor power – P_m = 90 kW;

4. number of cylinders in the telescopic hydraulic system – n_v = 3 (-);
5. the pressure applied to the telescopic system – p = 35 MPa;
6. extension of the telescopic system – h_{cp} = 4.8 m;
7. total length of the telescopic system – h_{ct} = 6.96 m;
8. the area required for the installation of the device – S = 250 m^2.

The maximum number of starts is proposed only as an indicative value, which should not exceed 200 starts per day. Thus, the total time of operation per day (7 hours) with breaks during boarding or disembarking passengers is provided by means of time of the ride multiplied by the maximum number of starts. The operator must only start the amusement machine when the attraction is as full as possible, the minimal occupation is when at least 1/4 of the circumference of the wheel is occupied. The distribution of passengers must be as even as possible around the circumference in order that the wheel is well balanced. Special specifications set out the main physical characteristics of the attraction [7,12,14]. We use formulae (1) to (7) to find these physical characteristics that affect the structure or the passengers. The period T is represented as a material point, in other words, 1 gondola occupied by passengers, which describes the circle 1 time. The formula (1) is used for the period T:

$$T = \frac{t}{n_k} = \frac{60}{14} = 4.286\ s \tag{1}$$

The angular velocity of the whole wheel ω_k is obtained by dint of formula (2):

$$\omega_k = \frac{2 \cdot \pi}{T} = \frac{2 \cdot \pi}{4.286\ s} = 1.466\ s^{-1} \tag{2}$$

We consider the circumferential speed of the wheel v_{ok} in the vertical position, where the wheel describes the largest diameter by tilting the gondolas during riding of amusement device. Accordingly, we can determine the desired diameter and the resulting formula (3) for the circumferential speed is subsequently:

$$\begin{gathered} v_{ok} = \frac{D_{ck}}{2} \cdot \omega_k = \frac{13{,}66\ m}{2} \cdot 1{,}466\ s^{-1}, \\ v_{ok} = 10{,}015\ m \cdot s^{-1} \end{gathered} \tag{3}$$

The angular acceleration of the wheel ε is obtained by the dividing angular velocity ω_k by the starting time t_r according to equation (4):

$$\varepsilon = \frac{\omega_k}{t_r} = \frac{1.466\ s^{-1}}{17\ s} = 0.086\ s^{-2} \tag{4}$$

The circumferential speed of passengers v_{op} is measured 0.6 m from the seat surface, and it is calculated based on formula (5), where D_{pk} is wheel diameter measured between two opposite gondolas at the passenger seat:

$$\begin{gathered} v_{Op} = \frac{D_{pk}}{2} \cdot \omega_k, \\ v_{Op} = \frac{11.214\ m}{2} \cdot 1.466\ s^{-1}, \\ v_{Op} = 8.22\ m.s^{-1} \end{gathered} \tag{5}$$

The acceleration due to gravity acting on the passengers a_p can be calculated according to equation (6), where r_{op} is the radius of the wheel measured between two opposite gondolas at the point of the passenger seat, g is the gravitational acceleration, F_{od} is centrifugal force of the gondola and F_g is the weight of the gondola:

$$\begin{gathered} a_p = \frac{F_{od}}{F_g} = \frac{\frac{m \cdot {v_{Op}}^2}{r_{Op}}}{m \cdot g} = \frac{{v_{Op}}^2}{r_{Op} \cdot g} \\ a_p = \frac{8.22^2\ m.s^{-1}}{5.61\ m \cdot 9.81\ m.s^{-2}} = 1.23g \end{gathered} \tag{6}$$

The calculated gravitational acceleration is considered in the equilibrium position of the device, inasmuch as the passengers get into the position when they ride in a vertical position downwards, the gravitational acceleration of the Earth must be added. The resulting maximum gravitational acceleration acting on the passengers is $a_{p_{max}}$ = 2.23g. These physical values are suitable for a rough description of the amusement device.

When designing the principal structural elements of an amusement device, the standard prescribes a condition of permissible deflection of the structure w_{per}, which the designer must not exceed (w_{per} = L/500, valid for all structural units carrying passengers, where L (cm) is the length of the verified structure) [2]. Verifications of the structure are performed at the most adverse effects of loads on the structure [7]. Welding is used to join many components of the structure [8]. The fatigue calculation for amusement devices assumes 35 000 operating hours without considering the time of boarding and disembarking passengers. Components of regular mass production (for example, bearings, large-sized slewing bearings), which are replaced more frequently, must be rated for 5 000 hours of operation. Structural components designed with a partial safety factor γ_{MF} = 1.1 (-) or 1.0 (-) are required to be checked periodically.

All parts subjected to pressure must be designed to withstand twice the maximum working pressure without permanent deformation or failure. Loads on pistons and cylinders are designed purely with regard to axial stresses. Telescopic jacks should be dimensioned in respect of buckling and the necessary acceleration of the telescopic system at the beginning and end of the stroke by creating a suitable reserve for increased load. In the event of a pressure line failure, the lowering speed must not exceed 1.0 $m \cdot s^{-1}$.

The proper operation of each amusement device is superintended by a minimum of two trained employees who are familiar with every aspect of the amusement device and supervised by a supervisor. During placement and construction, the supervisor must ascertain that the ground under the facility is sufficiently firm and nothing will hamper the movement of the attraction. Prior to installation, workers ascertain that all structural units are in fully functional condition and prepared for operation. The erection procedure should be carried out in accordance with the relevant drawings and assembly instructions. After the erection of the equipment, the supervisor personally inspects the assembly by means of the construction logbook and the manufacturer's instructions. In addition, it is essential to ascertain that the equipment is stable and stands firmly in place. Each amusement handling machine must be inspected daily in accordance with the logbook, in terms of some amusement rides this inspection may be more frequently. Moreover, the inspection includes a mandatory test run in order to check mechanical systems such as brakes, driving machines. The operator during operation checks all the requirements set by the manufacturer, for example the correct occupancy of the units, the passenger restraining before the start of the ride as well as ensuring that no passenger of an illegal age or height limit is allowed on the runway. The equipment must not operate in adverse wind speeds, the operator is required to check the wind speed sensor (anemometer) and stop the operation if the wind speed exceeds 15 $m \cdot s^{-1}$ [1-4]. Other values that specify the attraction will be determined in the further solution of this issue.

III. Main Structural Units of the Proposed Amusement Ride

The model of the amusement device (**Fig. 2**) is created in CATIA V5. The model is composed of 18 gondolas evenly distributed around the circumference of the wheel, on which 2 seats are secured. The gondolas are attached to a steel truss which is connected to each other by means of fixing profiles. The truss structure is slid onto the wheel hub and connected to it by dint of a rod with a manufactured thread.

The hub is slid onto an oversized hollow shaft and spun by means of an electric motor. The shaft is inserted into the prime beam, which is lifted to a vertical position through a hydraulic telescopic system. The hydraulic system is supplied with fluid by means of a pump with an electric motor. The hydraulic system will be equipped with metal hoses and two-way hydraulic lock in order to prevent damage of the amusement device (e.g., when critical elements of hydraulic system would fail). The connection of wheel hub and motor unit is depicted in the **Fig. 3**.

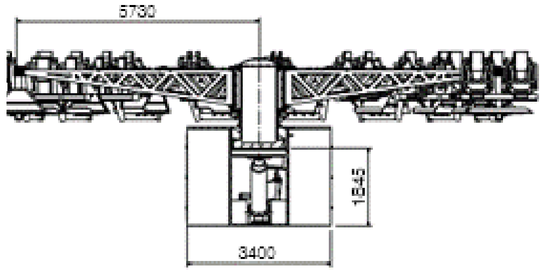

Figure 3. *The wheel hub and motor unit assembly*

A raised platform (podium) is built around the equipment for accessible boarding the gondola. The podium is a natural barrier from the point of view of preventing bystanders from touching the moving parts of the equipment.

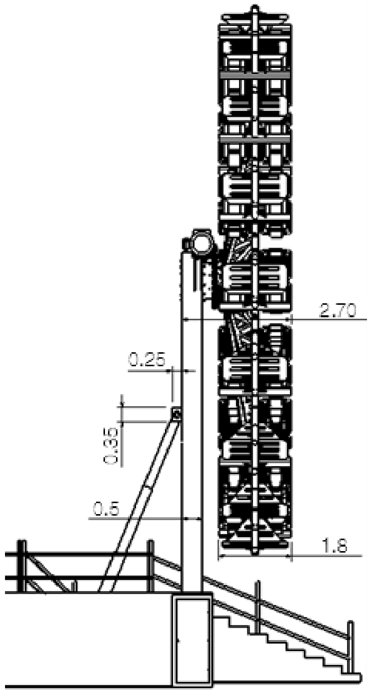

Figure 4. *Main dimensions of the proposed amusement ride – side view*

The entire machine covers an area of approximately 250 m^2, the wheel diameter is 13.584 m, the overall width of the amusement ride is 15 m, the width of the wheel anchorage is 3.4 m, the width of the gondola is 1.8 m. The distance from the outside of the wheel to the outside of the beam is 2.704 m. The width of the beam is 0.5 m. The mounting of the hydraulic cylinder on the girder represents a rectangle of dimensions 0.35 m x 0.25 m. The total height from the ground is 16.870 m. The height of the equipment from the beginning of the beam to the furthest part of the wheel is 15.325 m (**Fig. 4**) and (**Fig. 5**).

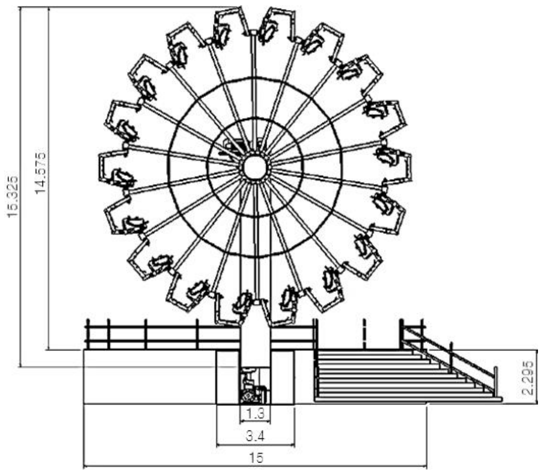

Figure 5. *Chief dimensions of the proposed amusement ride – front view*

The gondola shown in **Fig. 6** is designed for two passengers with a maximum load of 100 kg per passenger. The chief load-bearing parts of the gondola are constructed of structural steel. The basic load-bearing part is a tubular steel section CHS 150x5. This predominant part is welded to the beam of the SHS 150x10 (square hollow section). The seats are connected to the beam by steel sections transferring the load from the passengers to the main supporting section.

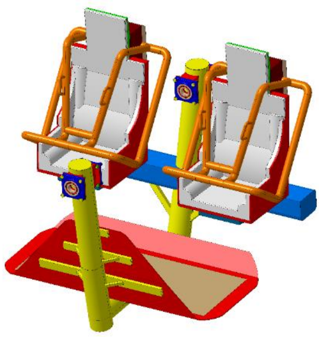

Figure 6. *A 3D CAD model of the gondola*

The seats are filled with foam that is covered with leather. A boarding plate is welded to the main load-bearing section. The boarding plate is employed for boarding the gondola and serves as a footrest in the course of riding. The plate is welded on rectangular profiles connected to the main supporting part of the whole gondola. A non-slip pad is glued to the boarding plate because of increasing safety when boarding the gondola.

The restraint depicted in **Fig. 7** is located behind the occupant's back and attached to the seat backrest. The restraint system comprises a restraint cage made of aluminium, which is operated by an electrical system with a mechanical safety lock. Cage is equipped with passenger handholds due to better withstand the forces generated in the course of riding. The cage is shaped in a manner that it does not apply pressure to fragile areas when holding the passenger and provides sufficient support in the event of the passenger falling out or being ejected.

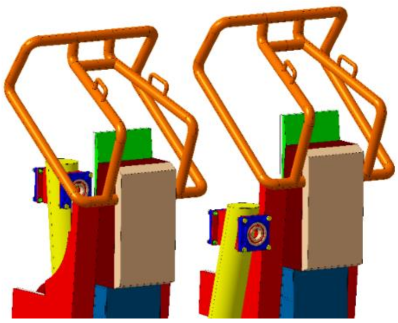

Figure 7. *Restraint system of the gondola*

The source of restraint system is placed in a protective box. The box is covered with metal sheets and secured against external unwanted influences. The bearing housings are fastened on the chief supporting part through 4 bolts. The housings contain single-row ball bearings (**Fig. 8**), which allow the gondola to tilt when the amusement ride is in motion. The threaded rod is pushed through the bearings, which is fixed to the truss structure and screwed with self-locking nuts. Spacer rings are placed between the truss structure and the bearing because of proper function of bearings.

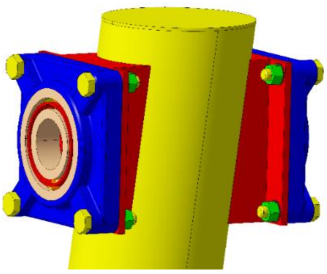

Figure 8. *Gondola bearing arrangement*

The truss structure (**Fig. 9**) is made of RHS (rectangular hollow section) 150x100x50 profile and S235 J0 material. The shape of the structure is made up of two prime members (chords). The upper member is 5.23 m long and at the end it is connected to the lower member, which is at an 8° angle to the upper member. Grips are welded on the upper member, between which the individual chords are joined together to form a single unit (wheel) by means of fixing profiles. The fixing profiles have a rectangular cross-section, where the shorter profile fastening the structure closer to the wheel mounting and the longer one fixing the truss closer to the gondola. Between the upper and lower members, the shorter members are arranged in a descending order at a 45° angle. The exceptions represent the first and last members, which are perpendicular to the upper long member of the structure. A hole is made in the first perpendicular member into which a rod is inserted. The rod connects the truss and the wheel hub. All parts of the truss are connected by welded joints.

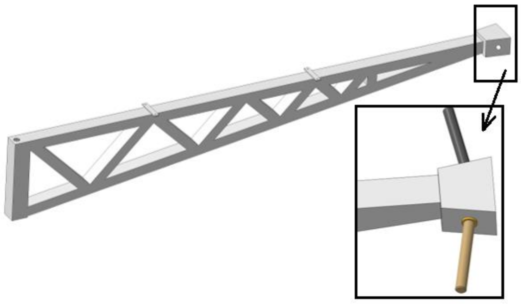

Figure 9. *Truss supporting gondola*

At the end of the structure is located a steel reinforcement in which the threaded rods are pressed (**Fig. 9**). The gondolas are suspended by these rods from steel reinforcement of the truss. The reinforcement is cut at a 10° angle in order that the bars are aligned on adjacent trusses, ensuring that the gondola can tilt.

The design of the truss structure, investigation of its maximum deflection and finding the most stressed member of the structure were the main objectives of the authors in the paper [21]. On the basis of the passenger body dimensions stated in STN EN 547-3 + A1, the structural design of the gondola of the amusement device (**Fig. 6**) was carried out, and the maximum load capacity of the gondola was determined to be 100 kg. Moreover, the restraint system of the gondola (**Fig. 7**) was designed with regard to ISO 17842-1:2023 standard. Subsequently, after assigning the materials, the mass of the gondola was obtained by means of Catia V5 software, approximately 705 kg. Further in the paper, the authors found and calculated the loads acting on the truss structure supporting the gondola, such as the centrifugal force of the gondola (where it was based on the calculated angular velocity of the wheel - equation (2)), the weight of the gondola, the centrifugal force of the truss structure itself. In addition, all load values had to be multiplied by the partial safety factor for variable effects, which takes values from the range (1.1 to 1.35), based on STN EN 13814-1 standard. The authors further set out to size the truss structure, based on STN EN 13814-1, which specifies the condition of maximum allowable deflection. Verification of the required deflection was performed by FEM simulation in Ansys software. Results (**Fig. 10**) demonstrate that the maximum deflection of the truss structure $w_{max} = 0.848\ cm$ was less than the allowable deflection $w_{allowable} = 1.05\ cm$ given by STN EN 13814 standard [21].

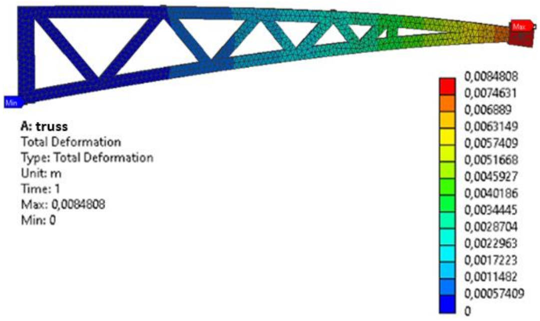

Figure 10. *The total deflection of the truss [21]*

The wheel structure of the amusement device is joined in the wheel hub. The hub provides the transmission of rotational motion from the motor to the wheel through the gearing. The primary component is an oversized hollow shaft fixed to the main beam of the device. A retainer is slid onto the main beam. Moreover, the holder is screwed against the shaft using eight M16 screws, which ensures that the hub is moved in the lower horizontal position of the device. The first oversized ball bearing is further slid onto the shaft. Further, the lower ring of the bearing is forced against a milled section on the shaft to ensure the bearing is functional. Before the drum is inserted, it is suggested to insert a spacer. The spacer ensures that the bearings do not move towards each other on the shaft. A shaped drum is slid onto the bearing on which the gear wheel is bolted. Flanges are welded to the drum, between which the individual trusses are inserted. After the drum has been inserted, a second bearing is embedded. A stop is made in the drum for bearing. The purpose of the stop is to prevent unwanted movement of the bearing as well as of the whole drum along the shaft. A retaining washer is screwed onto the end of the shaft for the sake of prevention of the overall movement of the second bearing out of the hub. Ultimately, a hub cover is fitted, which is screwed onto the drum. The hub cover has an oval shape and a lug by means of which is pressed against the drum as well as against the second bearing. The whole hub is made of steel and weighs approximately 5 tonnes (**Fig. 11**).

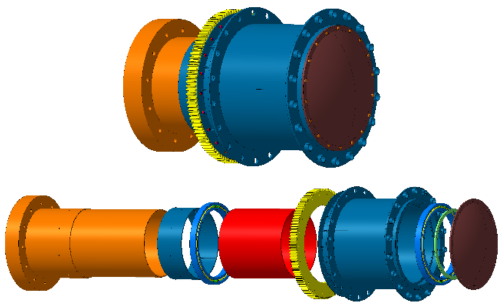

Figure 11. *Wheel hub (top – assembled, bottom – disassembled)*

The hollow shaft is inserted into the main beam 0.05 m and screwed with long M39 screws. Thus, the folded hub (**Fig. 11**) is approximately 1.5 m long. The shaft is stressed for bending in the vertical position of the device.

In the course of gear sizing, a spur gear with straight teeth (**Fig. 12**) was chosen. It can transfer a large torque from the motor to the wheel bearing due to the meagre losses. The small gear (pinion) is attached by dint of a tight key to the output shaft from the motor gearbox and secured by a washer with a bolt. The pinion turns the large gear attached to the wheel hub. The teeth on the large gear and the small pinion are designed with a modulus of m = 12 mm to withstand the high bending moment generated during the pinion and the large gear meshing. The axial distance between the gears is a = 0.792 m.

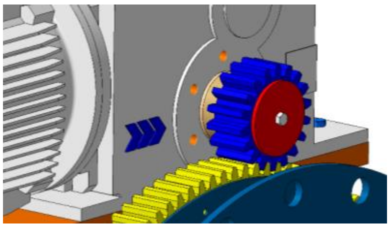

Figure 12. *The designed gearing*

The propulsion of the amusement device is provided by an electric motor with a bevel-front gearbox and a built-in brake (**Fig. 13**).

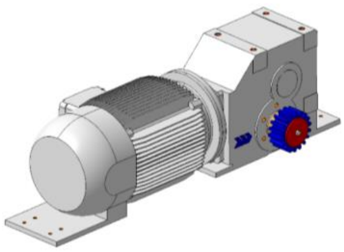

Figure 13. *Electric motor with gearbox*

The drive assembly is fastened on the primary beam by dint of 8 screws. The motor drives by means of the gear the wheel hub and spins the wheel to the desired speed. The change of the motor speed is ensured by selecting the frequency converter mounted at the control panel of the device. A self-powered brake is incorporated into the drive, housed at the rear of the electric motor.

The primary beam of the amusement device is made of S335 J0 steel and RHS profile (**Fig. 14**). The primary beam is fixed in the anchorage of the structure by a rod which is equipped with bearings. Therefore, this arrangement ensures a 90° change of column position. A catch is welded to the beam to which the hydraulic system is connected. The hole is manufactured at the top of the structure for the hollow shaft to slide into. In addition, the shaft is reinforced at the hole due to allow the material to withstand the full load from the wheel. Above the hole is a notch up to approximately half the width of the beam, where a steel plate is mounted against which the motor and gearbox are bolted.

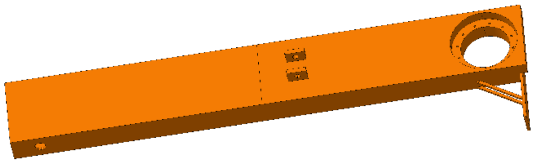

Figure 14. *A primary beam of the proposed amusement ride*

Another crucial element of the amusement device is the main beam. The authors aimed to scrutinise the main beam in the paper [22]. They performed sizing of the primary beam, analytical calculation as well as numerical calculation of the maximum deflection of the main beam, which must not exceed the permissible deflection given by the condition stated in STN EN 13814-1, namely $w_{per} = \frac{L}{500}$, where L is the length of the main beam. The value of the maximum permissible deflection is $w_{per} = 1.71\ cm$. The results of the maximum deflection of the primary beam obtained from the analytical calculations ($w_{max} = 1.59\ cm$) and FEM analysis (**Fig. 15**) are similar and less than the value of the permissible deflection [22].

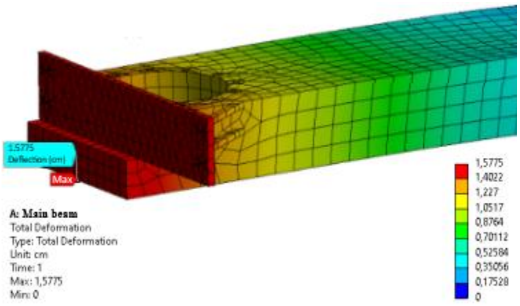

Figure 15*. A detail of total deflection of main beam [22]*

The hydraulic telescopic system (**Fig. 16**) is made up of 3 hydraulic cylinders. Extension occurs in the horizontal position where the system must overcome the greatest loads.

Hydraulic cylinder No. 1 starts pushing at a 50° angle over a length of 1.4 m. Hydraulic cylinder No. 2 starts pushing at a 46.88° angle over a length of 1.6 m and the last cylinder No. 3 starts pushing the beam at a 53.484° angle over a length of 1.8 m until the final position, in other words, until the beam is in the vertical position. The total extension length is 6.98 m. It is considered from the catch of the telescopic system. The hydraulic cylinders are attached at one end to mounting bracket placed at the upper part of the beam and at the other end in the anchorage of the whole amusement device. Liquid is injected into the hydraulic system at a pressure of 35 MPa through a pump driven by the electric motor located in the anchorage of the equipment. The oil is pumped from a collection tank attached to the anchorage and located above the pumping device. The kinematics of the proposed amusement device is graphically produced in the DMU (Digital Mock-Up) Kinematics environment in CATIA V5 programme. The amusement device can be defined by 4 positions when it changes its state.

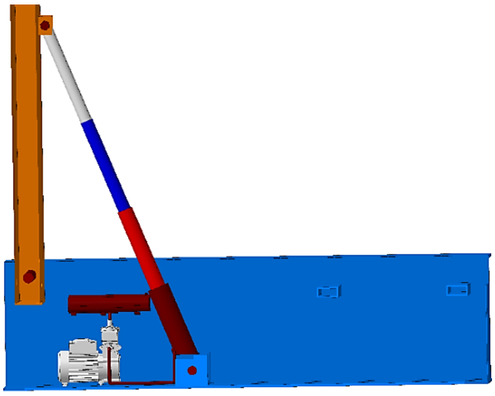

Figure 16. *A side view of the telescopic system*

The first position is the steady state, time for passengers to board or disembark, restraint attachment, start of the ride or end of the ride, as shown in **Fig. 17**.

Figure 17. *First position of proposed amusement ride [23]*

The second position occurs when the device is spun at a constant speed, before the lifting starts, when the tilting of the gondolas is observed (**Fig. 18**).

Figure 18. *Second position of the amusement ride [23]*

The third position is the one at which the device starts to raise or lower at the end of the ride by means of the telescopic system (**Fig. 19**).

Figure 19. *Third position of the amusement device [23]*

The last position – top, when the device reaches a vertical state, the gondolas are fully tilted, passengers ride in the upside-down position (**Fig. 20**).

Figure 20. *Fourth position of the amusement device [23]*

IV. Conclusion

The authors presented in the paper the analysis of the normative requirements necessary to perform the structural design of the handling machine serving the amusement industry. In addition, they demonstrated the technical specifications of the proposed equipment. Accordingly, they published structural designs of the diverse nodes of the mechanism and the kinematic possibilities affecting the occupants. In further research, the authors will focus on the dimensional calculations of the selected structural units by means of analytical and numerical methods.

Acknowledgement

This research was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 031ŽU-4/2023: Development of key

competencies of the graduate of the study program Vehicles and Engines.

AUTHOR CONTRIBUTIONS

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DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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REFERENCES

[1] Safety of amusement rides and amusement devices — Part 1: Design and manufacture, ISO 17842-1:2023 (2023).

[2] Safety of amusement rides and amusement devices – Part 1: Design and manufacture, STN EN 13814-1:2019 (2019).

[3] Safety of amusement rides and amusement devices - Part 2: Operation, maintenance and use, STN EN 13814-2:2019 (2019).

[4] Safety of amusement rides and amusement devices - Part 3: Requirements for inspection during design, manufacture, operation and use, STN EN 13814-1:2019 (2019).

[5] J. Bujňák, J. Vičan, Design of steel structures, (in Slovak), EDIS, Žilina, 2012.

[6] K. Woodcock, Human factors and use of amusement ride control interfaces, International Journal of Industrial Ergonomics, 44 (1) (2014) pp. 99-106. https://doi.org/10.1016/j.ergon.2013.08.009

[7] M. Rhode, Loads on and strengths of amusement rides, Steel Construction: Design and Research, 11 (3) (2018) pp. 232-239. https://doi.org/10.1002/stco.201810026

[8] R. Koňár, M. Mičian, et al., Numerical simulation of a temperature field during multi-beads surface welding, Journal of Applied Mathematics and Computational Mechanics, 20 (1) (2021) pp. 49-59. https://doi.org/10.17512/jamcm.2021.1.05

[9] H. Wen, I. Zhao, W. Chen, The Data-Driven Multivariate Process Monitoring and Diagnosis of Rides in an Amusement Park, in: Proceedings of 2018 12th IEEE International Conference on Anti-counterfeiting, Security, and Identification (ASID), Xiamen, China, 2018, pp. 136-140. https://doi.org/10.1109/ICASID.2018.8693125

[10] A. M. Pendrill, Mathematics, measurement and experience of rotations around three axes, European Journal of Physics, 40 (1) (2018) pp. 1-14. https://doi.org/10.1088/1361-6404/aaee22

[11] P. Stenzler, H. Handley, K. Woodcock, Identifying Human Factors Mismatches in Amusement Ride Containment Failure, in: P. Salmon, A. C. Macquet (Eds.), Proceedings of the Advances in Human Factors in Sports and Outdoor Recreation 2016 International Conference on Human Factors in Sports and Outdoor Recreation, Walt Disney World ®, Florida, USA, 2016, pp. 177-187. https://doi.org/10.1007/978-3-319-41953-4_16

[12] K. Woodcock, Determining participation eligibility for amusement attractions. Procedia Manufacturing, 3 (2015) pp. 5389-5396. https://doi.org/10.1016/j.promfg.2015.07.654

[13] K. Woodcock, Safety evaluation of amusement rides using accumulated accident data: Accident data framework, Journal of Themed Experience and Attractions Studies (JTEAS), 2 (1) (2022) pp. 40-53.

[14] K. Woodcock, Model of safety inspection, Safety Science, 62 (2014) pp. 145-156. https://doi.org/10.1016/j.ssci.2013.08.021

[15] B. Avery, D. R. Dickson, Insight into amusement park ride and device safety in the United States, Worldwide Hospitality and Tourism Themes, 2 (3) (2010) pp. 299-315. https://doi.org/10.1108/17554211011052221

[16] A. M. Pendrill, D. Eager, Velocity, acceleration, jerk, snap and vibration: forces in our bodies during a roller coaster ride, Physics Education, 55 (2020) pp. 1-13. https://doi.org/10.1088/1361-6552/aba732

[17] J. Zhang, G. Shen et al., Investigation on Acoustic Emission Characteristics of Steel Structure of Amusement Device, in: G. Shen, J. Zhang, Z. Wu (Eds.), Advances in Acoustic Emission Technology Proceedings of the World Conference on Acoustic Emission-2017, Xi'an, China, 2017, pp. 259-268. https://doi.org/10.1007/978-3-030-12111-2_24

[18] J. Harušinec, A. Suchánek et al., Design of a prototype frame of an electrically driven three-

wheel vehicle, MATEC Web of Conferences, 254 (2019) pp. 1-9. https://doi.org/10.1051/matecconf/201925402014

[19] M. Blatnický, J. Dižo et al., FEM analysis of main parts of a manipulator for mounting a compressor to a car equipped with a pneumatic suspension system, Diagnostyka, 21 (2) (2020) pp. 87-94. https://doi.org/10.29354/diag/122549

[20] Safety of machinery. Human body measurements – Part 3: Anthropometric data, STN EN 547-3+A1, (2009).

[21] M. Blatnický, D. Molnár et al., Design and Sizing of Structural Units of Technical Equipment Working in the Amusement Industry, Lecture Notes in Networks and Systems, 807 (2023) pp. 255-268. https://doi.org/10.1007/978-3-031-46874-2_23

[22] D. Molnár, V. Ishchuk et al., Dimensional calculation of the main beam of a technical equipment intended for the amusement industry, in: M. Rackov, R. Mitrović, M. Čavić (Eds.), The 12th International Conference KOD 2024 – Machine and Industrial Design in Mechanical Engineering: KOD 2024, Hotel Marina, Balatonfüred, Hungary, 2024, in review.

[23] M. Blatnický, J. Dižo et al., Analysis of normative requirements and technical specifications in the design of handling equipment for the amusement industry, in: P. Zimniak (Ed.), XIX International Technical Systems Degradation Conference: TSD 2022, Armed Forces Academy of general Milan Rastislav Štefánik, Liptovský Mikuláš, 2022, pp. 25-28.