Passenger evacuation concept as applied for the Munich Transrapid, taking particular consideration of possible fire incidents

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ABSTRACT: The “regulations for the construction and operation of Magnetic Levitation vehicles” (MbBO), in accordance with § 23, requires the submittal of a safety concept during the official approval and certification process, to the German Federal Rail Authorities. The concept indicates that for all visible hazardous situations, the statutory and operator’s safety requirements are met with support of the system’s features, specifically chosen safety and protection measures and the integral rescue concept. With reference to MbBO, the operator for the Munich central station to airport route project is the “DB Magnetbahn".

Along with designing the rescue concept, incidents, which could be regarded as extremely urgent, need to be considered. This is true as applied to persons remaining in the suspension vehicles during fire, as well as the evacuation at stations, tunnels and along the track. The rescue concept is based on the aspects of technical systems employed, the specific layout of the track, as well as the aspects depending on the specific situation. The conservative investigations concerning the possible consequences of an assumed fire incident in the vehicle result in specific requirements for technical fire protection in the vehicles, affecting the infrastructure and the operation itself. The requirements are collected, during the different life cycle phases in the project, through to the certification of the system. The specific safety and protection measures need special consideration when the effects to the overall magnetic levitation (Maglev) system are considered. Therefore corresponding processes have been defined, which result in the optimization of expenditure even when taking consideration of innovative solutions, with the implementation of simultaneous people-safety.

1 ASSESSMENT PROCESS

In accordance with §4 Paragraph (2) of the Regulations for Magnetic Levitation systems (MbBO), the approval of a safety concept is a crucial prerequisite for obtaining the operating licence from the German Federal Rail Authorities. The safety concept consists of a detailed hazard and risk analysis for the overall magnetic levitation system and describes the results of the quantitative risk evaluation for the potential hazards, as well as defines the safety and protection measures to prevent and lower the risks. Dangers associated with fire receive particular attention.

An integral part of the safety concept is a systematic overlapping rescue concept. This rescue concept bases upon the conditions provided by technical aspects of the system and the specific aspects of the track plus aspects referring to specific situations. Besides considering the technical rules, such as for example standards and guidelines similarly applicable to R/S vehicles, conservative assumptions for visible hazardous situations were made, so that the final decision is made on a safety-first basis. The rescue concept finally indicates that technical and operational safety is met in accordance with the traffic service regulations and by the desired measures.

The safety and rescue concept which has to be prepared by the contractor and approved by the German Federal Rail Authorities, pursuant to MbBO, has to be evaluated as the result of life cycle phase 3, in accordance with EN 50126. The concept specifies safety relevant requirements for further developments of the overall system and the sub-systems, along with the following life cycle phases.

In addition, the description focuses on the topics of passenger evacuation including the investigation of passengers’ self-rescuing and that of public rescue services. The main incident that needs to be considered is fire inside the magnetic levitation vehicle, since this hazard can result in dangerous high-risk situations for passengers and have serious effects on urgent processes.

The following remarks are made in accordance with a variance comparison and base on the results of an expert examination by TÜV Süd.
2 BINDING / SAFETY REQUIREMENTS

The rescue concept shows that the possible fire incidents and/or fire scenarios can be controlled and are acceptable in their results, under consideration of the constructive conception of the magnetic levitation (Maglev) system and its technical concepts for fire protection (refers to infrastructure and vehicles). Associated with this is the safe operation of the vehicles, especially when discussing the protection of people. Thus, all fire incidents caused by technical (e.g. fault with arcing effect) or by persons (e.g. negligence), have to be considered when determining their potential to lead to dangerous situations.

Operation, vehicles and infrastructure have to collaborate and meet the safety requirements set up by the authorities and the contractor (e.g. risk acceptance criteria). Additionally, the particular requirements of operating the Maglev vehicle with non-availability of staff, needs to be considered.

2.1 Requirements needing to be met for the rescue concept

People must escape as quickly as feasibly possible from the area of fire initiation. Owing to the general use of the Maglev vehicle, by the general public, (cf. MbBO § 3 article 3, § 15 article 6 and § 17 article 1) the requirements of handicapped persons also need to be considered.

Thus, the process „self-rescue of mobile passengers“, inside and outside the vehicle is raised. Depending on the position of the vehicle, fastest possible support and/or rescue of handicapped and possibly injured passengers who are inside the Maglev vehicle might be necessitated.

Additionally the stopping point of the Maglev vehicle has to be safeguarded in the fastest possible way, so that further danger is avoided.

Consideration needs to be taken of the fact that passenger’s who get into contact with a fire incident, have differing evaluations of the situation and therefore react in different ways. Additionally when acting and reacting they are widely dependant on themselves and the instructions of the remote works operation management, as a result of the guideless operation of the vehicle. The individual behaviour in a dangerous situation, owing to the instinct of self-preservation, has to be generally evaluated as irrational. People exposed to such a situation can well-be in a state of panic. Therefore, specific precautions have to be taken.

This relates to marking the position and the operation instructions of aides and device. Thus, the probability that passengers use the fire extinguishers to fight the arising fire will be increased.

This concerns bidirectional communication between passengers and staff, which are located in the operation control centre. The video control system installed in the Maglev vehicle helps the staff to get an overview of the situation. Thus, the operation manager can encourage the passengers via the loud-speaker system to act and/or give instructions for the evacuation process.

Furthermore it needs to be demonstrated that in the case of a fire situated in the Maglev vehicle, the reliability of system specific technical functions has to be maintained and that the concerted continuation of the service e.g. to the next evacuation stop or to the station is possible. Thus further risk for the passengers during evacuation in tunnels or on the track, getting off the train with the help of onboard emergency equipment, can be largely avoided. Thus rescue services, provided by fire brigades, and further on remaining in service, can be dispensed with.

2.2 Requirements for passenger-areas inside the vehicle

Greatest possible safety of persons has to be guaranteed. This means that the danger to people’s health in the passenger areas inside the vehicle during the time of self-rescue and rescue by public services has to be limited to a minimum. Consideration has to be given to how long people remain in the vehicle when they continue their journey to the evacuation area, and the time period duration till the end of evacuation.

As a result of fire, toxic smoke will produced, which should not lead to the incapacity of persons remaining in the compartment. In all cases, the passenger should remain capable of self-rescue. One needs to keep in mind that the physical reaction during the inhalation of toxic smoke is dependant on the mental (hectic acting leads to hyperventilation) and physical conditions of people (children, elderly people have a smaller inhalation volume), as well as on how long (blood gas concentration) people stay in the zone filled with smoke.

Hence, the significant aspect in the evaluation of the possible influence of fire remains the formation of toxic smoke. In addition, the release of carbon monoxide and carbon dioxide, as well as cyan-hydrogen is the centre of discussion and / or the actual risk for the passengers’ health. All others toxic gases are rather insignificant providing that the value of the gas share of 0.8 vol. % of carbon-monoxide is not significantly exceeded.

When evaluating the construction of the vehicle, regarding the aspects of fire protection, the examination is focused on the construction materials used and the technical equipment used for fire protection.
During operation, other inflammable as well as highly inflammable materials (e.g. baggage or clothing), will be inside the vehicle. The burning of these materials, in reality, results in differing composition of the emitted smoke. The requirements of the standards focus too closely on the toxicology of the construction materials used. For this reason, the following limiting values have to be considered, when evaluating the location of fire, inside the vehicle:

Table 1: Target values and limiting values for a room

<table>
<thead>
<tr>
<th>Fumes' share</th>
<th>Target value 1/1</th>
<th>Limiting value 1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>&lt;400 ppm</td>
<td>1400 ppm</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>&lt;0.8 Vol.%</td>
<td>6 Vol.%</td>
</tr>
<tr>
<td>Cyan hydrogen</td>
<td>&lt;45 ppm</td>
<td>50 ppm</td>
</tr>
<tr>
<td>Oxygen</td>
<td>&gt;14 Vol.%</td>
<td>12 Vol.%</td>
</tr>
<tr>
<td>Fumes’ temperature</td>
<td>&lt;60°C</td>
<td>65°C</td>
</tr>
<tr>
<td>Optical fume density</td>
<td>&gt;0.2 m⁻¹</td>
<td>0.3 m⁻¹</td>
</tr>
<tr>
<td>And/or range of sight</td>
<td>&gt;10 m</td>
<td>15 m</td>
</tr>
<tr>
<td>Thermal radiation</td>
<td>&lt;0.3 W/cm²</td>
<td>0.5 W/cm²</td>
</tr>
</tbody>
</table>

With the help of simulation tools and practical fire tests, simulating fire analyses can be performed to estimate the effects of smoke. In order to achieve results as close to reality as possible, the object that causes the fire has to be defined and the burning characteristics of the materials located around the fire, have to be known.

3 PRECONDITIONS FOR THE ANALYSIS OF THE ACTUAL SITUATION

3.1 Fire occurrence due to vehicle technology

Despite optimized technical concepts, regarding fire protection in Maglev vehicles and the use of modern systems and materials, one has to take into consideration possible fires caused by technical faults during actual operation of the vehicles.

Technical systems are exposed to external influences. Therefore it is possible that previously unidentified operational parameters (e.g. vibration) could cause possible operational deficits, e.g. loosening of electrical connections in electrical units. This can lead to an overheating of electronic modules and in turn lead to heavily inflammable materials igniting. These fire incidents usually remain invisible for the passengers inside the vehicle. However they can also suddenly appear, as smoke and occasionally, as flames. Furthermore, fire can cause malfunction of other technical functions and the journey could thus be interrupted. The Maglev system is designed with special respect to safety aspects, so that failures result in deceleration of the vehicles. A safe stopping point guarantees convenient evacuation and a safe system state.

Therefore, a comprehensive fire risk analysis has been performed. In so doing, all components that can cause fire when defective have been evaluated.

The result clearly shows that malfunctions lead to limited fire incidents. Functionality of the technical diagnosis (e.g. supervision of current or temperature), usually result in automatic disconnection of the affected unit, or of the total technical system. Such a situation does not result in discontinuance of the journey, of the vehicle. The smouldering fire, which had developed by then, will quench owing to missing ignition energy. Additionally all significant technical components are built, separated from each other, inside metallic housings, according to aspects of fire protection, so that a possible flaming fire cannot emerge from these. The fire risks illustrated in figure 1 thus do not represent a hazard. Therefore, the fire remains constrained to its container and could be regarded as acceptable in its effects.

Figure 1: Opened casing of a magnetic-regular-unit for „meet-to-carry”, with indicators showing possible igniting points.

The control and data cables as well as the central cables of the power supply are installed and protected in a way, that they are only damaged superficially in case of fire. The functionality, however, is maintained for the specific period of time.

Hence the vehicle can still reach a more favourable area, for evacuation, such as an evacuation stopping area, or the station, in case of a possible fire in the technical system.

3.2 Fire occurrence in the passenger compartment

Fire in passenger compartments can basically only occur due to carelessness or arson (e.g. sabotage). The construction materials, which are used, have characteristics, which are sufficiently resistant to fire owing to the fire protection selection criteria imposed by the accepted technical standards. Of particular concern is the flammability when exposed to general igniters such cigarette ends or the flames of lighters. The extent of the fire is also limited.

The main risk of fire is related to easily flammable fire-transporting materials such as luggage and clothes, in the vehicles occupied by passengers. It cannot therefore be precluded that these materials, on fire initiation, further transfer the fire to heavily flammable construction materials. Therefore, a travelling bag as fire initiating item, was placed in a lo-
cation, where luggage can be centrally deposited, was used for the investigation (see Figure 2).

Under conservative aspects, the investigation is focused on the passengers travelling in the end section of the train, since all other fire zones can be classified as controllable within the scope of the rescue concept. Due to unfavourable fire conditions in the area between an end and middle section, the passengers cannot escape to neighbouring compartments.

Figure 2: Assumed fire locations in the passenger compartment of the vehicle as an assumption for the fire simulation

Hence, these people are directly exposed to the smoke that arises from the fire (concerns toxicity and temperature). To assess the possible situations, a representative fire scenario for the “passenger compartments” was set up. This was also done in accordance with the regulations of the future European standardization prEN45545. In doing so, actual fire tests have been performed in an accredited testing laboratory (MFPA Leipzig), so that sufficient data for theoretical fire simulations are available. The defined fire scenario smoke passages (see limit values in table 1) are also considered.

In the result, criteria for a representative „traveling bag“, were defined, which is the initiating fire for the following fire simulations in a room:

1. Continually rising heat release by minimal 120 kW after 5 minutes
2. Minimal fire load of the bag of 136 MJ with a thermal value of about 21 MJ/kg
3. 100 g Newspaper have an initial effect (acc. to UIC 546-2) laid on top of the bag.

When the travelling bag starts combusting, the seats as a consequence, are set alight after about five to six minutes. Owing to the extreme heat energy release, heavily inflammable materials such as the interior walls as well as the ceiling are also set alight.

The example simulation in Figure 3 shows that the fire extinguishes on its own due to a lack of oxygen, after passengers are evacuated into the adjacent section.

Figure 3: Actual fire applied to a bag and simulation of the activation of neighbouring flammable materials

The simulation tools KOBRA-3D (field model – I.S.T Frankfurt), MRFC (zone model – TU Vienna) and FDS (field model / Fire Dynamics Simulator – NIST USA) were applied. All programmes are widely accepted and have been applied e.g. for simulations in buildings.

The effect of smoke and the impediment of people’s capability to act were assessed and/or estimated in accordance with the method of PURSER (Manual Society of Fire Protection Engineers of NFPA USA). This was originally compiled for the evaluation of aircraft applications.

Figure 4 shows the results of calculations made from the simulation data assessed with the tool KOBRA-3D. The dashed line represents the limiting value for the start of the incapacity to act, according to PURSER.

Figure 4: Result of the simulation in relation to the effects of smoke in the area between two sections

Example results of a simulation of the burning travelling bag in an area between two sections are depicted in Figures 5 and 6, for two different moments during the fire. The increase of smoke-temperature as well as the density of emitted smoke is shown in the same time frame.

The results of the detailed computer simulations indicated that no critical situations arose for people’s health within a period of up to eight minutes. This includes the evaluation of the concentration, density and topicality of smoke in the fire affected sections, as well as the possible orientation of the passengers in the section during evacuation to neighbouring relatively safe sections. Therefore the MbBO re-
quired minimum 30 minutes occupation time is guaranteed.

Figure 5: Simulation result after two minutes (picture shows a distance of 30 cm to the side wall)

Figure 6: Simulation result after eight minutes (picture shows the middle of the vehicle)

It has been possible to confirm the plausibility of the theoretically assessed data, by vast experience and parameters collected in other 1:1 fire tests in rail vehicles. Hence the results of the simulation are plausible.

4 EVALUATION OF PASSENGER EVACUATION

The fire simulation served to show that smoke development for a period longer than eight minutes (toxicity and temperature) do not affect the passengers’ incapacity to act. Even smoke density still allows orientation inside the room that is affected by the fire. Therefore a self rescue out of the fire affected section/s to neighbouring sections and/or to the evacuation platform in the station is possible.

The simulations for evacuation inside the vehicles were intended to show that all passengers of a section could rescue themselves into neighbouring zones of “relative safety”. To illustrate this, two different tools for evacuation simulation were applied. All evacuation scenarios were re-calculated in accordance with the calculation method of PREDETSCHINSKI/MILINSKI (hydraulic model – applied for buildings) and the simulation tool: PedGo (multi-agent-model – certified by the International Maritime Organization IMO).

Along with the hazard analysis, both fire scenarios, shown in Figure 7, were assessed as the incidents with the highest endangering potential (worst case).

Figure 7: Evacuation of the middle section and investigation of the tailback situation in the end section

These two were analyzed in detail, again with self-rescue being assumed in a single direction. Additionally, a maximum vehicle capacity of 412 passengers was assumed, which would rarely be encountered on revenue service trips.

The time to completely evacuate passengers from the middle section into an end section, including reaction time of 164 persons, amounts to about 4.2 minutes. Comparable real evacuation tests resulted in a time period of about two (fast) up to five minutes (slow).

In case of fire in the end section, it is assumed that the evacuation, after the vehicle has stopped, can only be performed from the section affected by fire through a single vehicle door. Taking the conservative case that the fire begins at the most unfavourable time, the journey to an evacuation stopping area takes a maximum of six minutes. Simulations of evacuations show that it takes about two minutes for 142 persons to get out of the vehicle. Even here comparable real life tests, with trains at platforms, show similar results, so that the result is considered to be feasible.

In the case of the fleeing directions of people getting mixed up at the evacuation stopping area, at the vehicle door of the end section, evacuation time is extended to 2.5 minutes. This situation is depicted in figure 8 as an example showing a time sequence.

Figure 8: Evacuation of the Maglev vehicle in a fire located in the bend section of the intersection of two zones

When considering the maximum length to stay in a burning vehicle, of eight minutes in a section, during the fire simulation, it became clear that the operational-staff in the control center have to pass-
on information aimed at the passengers in the vehicle. Only in doing so a tailback situation in the section, which is affected by the fire, is prevented.

**Conclusion:**
Fire formation, owing to carelessness, can hardly occur due to the vehicle being marked as a non-smoker zone.

In case of a large volume of traffic „social control“, imposes its effects, so that fires being started, are unlikely. The conservative assumptions (worst case) for the simulation, such as highest number of passengers, most unfavourable fire position, and longest journey until evacuation, render sufficient resources of safety. The results show that the safety requirements can be met.

5 OPTIMIZATION OF VEHICLE TECHNOLOGY

The installation of an autonomously operating fire detection system in the passenger compartment sections, make it possible to suppress possible fires in the initial phases. After the detection of smoke, high-pressure water fog is released into the area, which is affected by the fire, through nozzles, which are installed in the interior ceiling. In doing so the smoke, which has already arisen, and the flaming that has occurred, is limited during the emerging phase.

Owing to automatic fire fighting, dangers arising from the fire and directed towards the passengers, are limited to a minimum. Thus, it is safe to also remain in the sections, which are affected by the fire. Additionally there is an optimization potential for the technical concept, so that fire protection measures such as fire-proof doors between the sections, which had originally been planned, can be dispensed with, after reassessment of the risks. The following figures show the efficacy of the technology by means of comparison tests, which had been carried out at a 1:1 scale.

In applying this technique – references to other rail vehicles are already available – the utmost possible safety is attained.

6 PROOF OF FUNCTION

As soon as the Maglev vehicle has been constructed, the technical facilities and processes, in the course of certification for their specified functionality, and in collaboration with infrastructure and the operational requirements, have to be proven. This affects, for example:

- Real fire testing, in relation to the characteristics of the material, for the fire-proof effect of line replacement units or for the validation of the fire-fighting system
- Simulated fire testing in order to prove the functionality of fire-detecting technology (see Figure 11), as well as of the disconnecting function of the air-conditioning unit
- Real-life testing with test passengers’, e.g. to try out the handling of rescue aides and for the evacuation of the Maglev vehicle (see Figure 12) e.g. in tunnels and at the evacuation stopping areas. Additionally the sequence of emergency and rescue concept, have to be verified for their practicability. This for example, covers the collaboration of technology and operational staff, as well as of the rescue team.
Additionally the procedures with regard to the emergency and failure concept are checked for plausibility. This would for example encompass the interplay of the technical system, the operations staff and the rescue services.

The currently planned technical and operational concepts, with reference to the requirements of personal safety in accordance with MbBO, the safety requirements of the DB AG and the recognized technical rules, lead to the expectation that the fire protection is conclusively dealt with.

References to other rail-bound vehicles that implement the fire fighting techniques are available and thus the maximum possible safety of the passengers is attained for a fire incident.

7 CONCLUSION

Owing to the systematic and analytical methods to set up safety measures for the reduction of risks, and owing to the application of modern technology and materials in the vehicle, as well as usage of an automatic operation control system, the Maglev system attains a very high level of safety.

As soon as the safety measures have been implemented, a „State-of-the-art technology“, is reached by the innovations, which due to the differences between the Maglev system and that of the standard wheel-rail systems, exceed the currently known technology guidelines.

Even now, the application of innovative assessment methods currently unknown to have been applied in the rail sector, are possible. Hence standards had been, and will be set, for the future. The costs arising as a consequence are rather low compared with other assessment methods. The assessment methods can be taken as standards for the “proof of the equivalent safety”, so that synergetic potentials can be exploited. In the final conclusion therefore, reduction of costs in the certification process with a higher level of safety are possible.

8 REFERENCES

/1/ Guideline - Ingenieurmethoden des Brandschutzes Ref. 4 der VFDB (Entwurf – 10.2005)
/2/ Guideline „Bemessungsbrände“, Verband der Sachschutzversicherer VdS 2827 (05.2000)