Crash Safety System of the Maglev Vehicle

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**ABSTRACT:** In the last decades great efforts were made in the automobile, aircraft, railway and shipbuilding industries to improve the safety of traffic systems [1]. Based on the accumulated knowledge of crash and impact safety structures, a new type of crash safety system for maglev vehicle has been developed by ThyssenKrupp Transrapid and Technische Universität Dresden.

This article describes the experimental research results of various kinds of materials and structures under a certain crash speed and load of maglev trains. The quasi-static material properties for the numerical simulation are examined. The stress and deformation of the crash safety system are investigated in consideration of the defined crash scenario, the normal operation as well as worst running conditions. Modal analysis to improve the dynamic behavior of the whole crash safety system is included.

By using the new structure and material, the developed crash safety system of the maglev vehicle has about 35% lower weight. The crash impact to the vehicles’ levitation frame is decreased by about 58% compared with the crash system of the previous generation. The manufacturing is also essentially simplified.

1 INTRODUCTION

The transrapid is the safest transportation system with high speed in the world. Unlike railway systems, it is virtually impossible for a maglev train to leave the guideway because the levitation and guidance system of each vehicle wraps around the guideway. On the other hand, a collision between two maglev trains is technically impossible, as the principle of the transrapid long stator linear synchronous motor excludes the possibility of a collision between two maglev vehicles running at different speed in the same direction or traveling in opposite direction in the same motor section [2]. Furthermore, Right-of-way will be maintained free of trees that would fall onto the guideway.

If these objects had a large size as trees or big animals, they would collide with the nose area of the maglev vehicle (figure 1). The special frontal construction would reflect the encountering objects to the guideway side, the collision energy on the maglev vehicle could be absorbed by the foam structure strengthened with Kevlar fiber.

If the encountering objects would have a relative small size but heavy weight as stones, they might penetrate the frontal sub-floor structure of the vehicle. In these cases, the crash safety system in the front of the maglev vehicle can absorb the crash energy of the heavier objects. In this article a new type of crash safety system for the sub-floor structure of the maglev vehicle developed by joint effort from ThyssenKrupp Transrapid and Technische Universität Dresden will be introduced.

2 COLLISION EFFECT

The potential collision of the maglev vehicle with external objects is considered with a representative spectrum of “foreign objects” as trees, biological bodies or stones on the guideway. These obstacles could intrude into the clearance profile by environmental or external influences. Under the condition of the collision with heavier objects at a speed of 500 km/h, the crash safety system of the maglev vehicle...
must be designed in the way that the collision effect is minimized to passengers. The technical requirements of the collision behavior with representative objects which are defined in the safety requirements [3] are specified as follows:

- Maximal deceleration in the passenger compartment less than 15 m/s² at a running speed of 500 km/h;
- No components separated from the vehicle to wedge the running vehicle;
- No break-off of the skids or magnets from the vehicle structure;
- No deformation of cable channels resulting in failure of the maglev vehicle safety functions;
- Collision deformation is limited to the vehicle nose area;
- After collision the maglev vehicle would take passengers to the next station and run in the maintenance centre for inspection, repair or exchange of the affected component groups.

In order to fulfill these safety requirements, the material and the structure of the crash safety system as well as the collision behaviors of the maglev vehicle with various kinds of potential objects have been investigated by means of experimental and numerical simulation.

3 MATERIALS AND STRUCTURE OF THE CRASH ELEMENTS

Crash worthiness has been a major concern in the transportation technologies during the last decades. Many researchers all around the world have been creating extended knowledge on the development of crash and impact safety structures, contributing to understand and dominate the large energy and forces involved during a crash/impact event and to improve safety of passengers of all kinds of transportation. Compared with the maglev vehicle, the crash/impact speeds of automobile, train or ship are relatively small and the effective impact area is relatively large. Even the collision structures of airplane are usually designed only for landing at relatively low speed [4].

In the automobile industry there are many kinds of bumpers available today; they are being usually mounted on the front and rear part of vehicles to provide sufficient protection to passengers during collisions. Due to the large crumple zones and the deformation of the cross beam in the impact configuration, much energy can be absorbed [5]. According to the modern concept the lightweight structure reinforced by fiber will be utilized to increase the stiffness of the frontal structure, the collision forces will be transferred to the longitudinal structures of the vehicle to enlarge the crushing and deformation area [6] [7].

The challenge to the crash safety system in the maglev vehicle lies in the very high speed and the small impact area in the structure with stones. The kinetic energy of the collision stones is so gigantic that any possible cross beams will be quasi pierced, without being able to transmit the energy to the supporting structure. Therefore a laminar structure is necessary for the maglev vehicle. Such structures have been applied for instance in the sub-floor structure in aircraft to absorb the kinetic energy in the case of landing collisions [8].

In the sub-floor structure of aircrafts, the composite materials which are reinforced by fiber in four layers have been used. Unfortunately these materials are not suitable for the small compact area in the maglev vehicle at high speed. The classical solution for the crash structure with high-strength steel in the automobile industry leaves also out of consideration because of the high collision speed of the maglev vehicle.

The material for the crash element used in the maglev vehicle must have not only the character of very good specific energy absorption, but also the properties of lightweight, fire and corrosion proofing, low cost and easy manufacturing. To investigate the suitable material and structure of the crash elements, a series of experiments have been carried out with the impact test facility in the Technische Universität Dresden, as figure 2 shows.

![Figure 2: Impact test facility.](image-url)
The impact test facility consists of a rigid back wall and a long acceleration tube. The testing materials and structures fixed on the back wall will be shot by a bullet with defined mass, size and speed. Various materials such as aluminum, composite material, timber, Kevlar fiber cloth and elastomer as well as sand have been examined. Figure 3 shows the crashed specimens with different kinds of materials and structures.

The results of the experiment show that the crash structure made up of closely packed aluminum pipe has efficient energy absorption for the quadrate impact object, but it is not suitable for the spherical impact object, as derived from the simulation results shown in figure 4 and 5.

As expected the plastic foam indicates high specific energy absorption ability under the crash condition specified in maglev vehicle, however, it is difficult to apply because of the property of the not approving fire proofing. Although the new material of metal foam would solve this problem elegantly [9], due to commercial reason its industrial use is not realistic at present. On the other hand, the investigation of the material parameters for the crash simulation is not sufficiently.

As a further group of materials with efficient specific energy absorption ability, aluminum honeycombs offer an interesting alternative. They can be attributed a nearly constant crush force and provide a very repeatable crush performance. Furthermore, the aluminum honeycombs have a very high crush strength-to-weight ratio, about 75% of its thickness can be crushed. Moreover they can be easily processed into finished components [10].

The tested aluminum honeycombs are shown in figure 6, the deformation depth increases with the raising speed of the bullet. The bullet penetrating the honeycomb in the figure 6d has been barricaded by the plate adhered on the honeycomb structure. The available material parameters both for the static computation and for the crash simulation have been examined by experiment results at various crash speeds [11]. According to the experiment and simulation results, the aluminum honeycombs will be used as crash elements in the maglev vehicle.
4 STRUCTURE OF THE CRASH SAFETY SYSTEM

The crash safety system consists of one middle crash box and two side crash boxes which protect the skids of the maglev vehicle. Two snow deflectors installed on the side crash box ensure the normal operation of the maglev vehicle in the case that snow thickly accumulates on the guideway. The whole system is fixed on the first levitation frame of the maglev vehicle.

The outer covering of the crash boxes are made up of aluminum plates which are riveted with each other, and the aluminum honeycombs which are arranged in a laminated structure with shims are fixed in the inner.

The design of the bottom structure of the crash boxes minimizes the exterior and interior noise caused by aerodynamic effects during the high speed running. The strength and deformation of the crash boxes have been analyzed under different mechanic loads such as aerodynamic pressure applied on the structure bottom, dynamic load as well as the force resulting from the snow deflectors. Furthermore, the natural frequency of the crash box has been investigated to avoid mechanical resonances at the normal operation speed. As an example figure 8 shows the distribution of the absolute deformation of the crash box under the maximal aerodynamic pressure.

By means of the finite element method the structure of the crash boxes have been optimized in consideration of various kinds of mechanical loads. The structure and their manufacturing are essentially simplified. The weight of the crash boxes and the crash force are considerably reduced in comparison to the previous generation of the crash system.

5 CRASH SIMULATION

Figure 9: Crash simulation of the side crash box with a 15 kg cuboids stone, speed of the maglev vehicle: 500 km/h.
As an example of the crash simulation, the mechanical behavior of the crash safety system collided with a 15 kg cuboids stone on the side crash box is calculated by means of the finite element method. A collision of the vehicle with a 50 kg spherical stone on the middle crash box is also simulated.

The aluminum honeycombs are modeled with volume elements, the surface layers with shell elements, and each rivet is simulated with a special pipe element. The anisotropic material parameters of the honeycombs examined by experiments are applied in the simulation. The levitation frame of the vehicle is additionally contained in the model, its mechanical property is treated as elastic-plastic material.

The crash simulations are carried out with the program LS-DYNA. Figure 9 shows the calculation results of the crash between the side crash box and a 15 kg cuboids stone at a vehicle speed of 500 km/h. The guideway is regarded as a rigid and friction-free surface.

The cuboids stone breaks into the side crash box, while the aluminum plates and honeycombs are strongly distorted, crushed and sheared. The other parts of the whole crash box have hardly any deformation. After about 26 ms the cuboids stone could move at the same speed of the maglev vehicle.

Figure 10 shows the velocity relationship between the cuboids stone and the levitation frame of the maglev vehicle during the crash process. The major amount of the deceleration of the cuboids stone occurs within the first 13 ms. According to the calculated collision force, the maximal deceleration in the passenger compartment is less than 0.1 m/s^2 which is essentially smaller than the allowed value.

The simulation results of the crash between the middle crash box and a 50 kg spherical stone at a vehicle speed of 500 km/h are shown in figure 11. The most significant amount of the kinetic energy of the collision stone is absorbed by the crash box, the left little amount could have an effect on the levitation frame. Figure 12 shows the development of the velocity of the collision stone and the levitation frame in relation to the crash time. The calculated crash forces on the stone and the levitation frame are illustrated in figure 13.

Figure 11. Crash simulation of the middle crash box with a 50 kg spherical stone, speed of the maglev vehicle: 500 km/h.
In consideration of the connection stiffness and the damper between the levitation frame and the vehicle compartment, the mechanical behavior of the passenger compartment has been analyzed. Due to the efficient absorption of the crash energy in the crash safety system, the velocity change of the passenger compartment is neglected small, as shown in figure 14. Because the maximal deceleration is less than 0.25 m/s², the collision might not catch the passengers’ attention.

To avoid the mechanical resonances of the crash safety system at the normal operation speed, modal analyses have been carried out. Figure 15 shows the schematic deformation of the crash box at the first global natural frequency located at about 80 Hz. This value ensures a considerably large reserve compared with the allowed minimal frequency.

In conclusion, various kinds of material and structure for crash boxes have been investigated experimentally and theoretically to develop a sufficient crash safety system for maglev vehicle. To reduce the weight of the crash safety system, its structure is optimized in consideration of the defined crash scenarios, the normal operation as well as worst running conditions. Modal analyses are carried out to avoid the mechanical resonances at the normal operation speed.

The mechanical behavior of the passenger compartment is simulated during the crash process. The crash safety system is so efficient that the velocity change of the passenger compartment is neglected small. The new developed crash safety system can fulfill all technical and safety requirements of the maglev vehicle.

At present the composite materials reinforced by fibre are being intensively studied for crash and impact loads all around the world [12]. To decrease the structure weight further, these materials could be applied in the crash safety system of the maglev vehicle in the future.

7 REFERENCES


