Innovative Drive and Guide Concept for Experiments under Microgravity in the Einstein-Elevator

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ABSTRACT

The Einstein-Elevator is a novel earthbound facility for conducting scientific experiments under microgravity. It is a modification of the classical drop tower, whose free-fall simulation is based on a novel and worldwide unprecedented drive and guide concept. An experiment placed in an evacuable gondola is vertically accelerated, then following a parabolic flight path. Rolling resistance and air drag acting on the gondola are compensated by a linear direct drive. The drive also generates the high acceleration forces required for launching the experiment. After the vertical parabolic flight, experiment and gondola are decelerated and centered at zero speed to prepare for the next experiment. With this drive concept, a repetition every 4 min is possible, amounting to 100 experiments per day.

The high standards required for carrying out scientific experiments under microgravity imply complex structural measures that will be described within the scope of this paper. Furthermore, the interfaces to the building, the guide arrangement of gondola and drive, position transducers as well as the gondola's design and the experiment carrier are presented. Finally the requirements related to the building are given.

Einstein-Elevator, tower-in-tower construction, drive and guide concept, linear direct drive, minimum residual acceleration.

1 INTRODUCTION

The Einstein-Elevator, a large-scale research facility, is a free-fall simulator being developed for conducting fundamental physical experiments and doing further experimental research under microgravity conditions, also under consideration of scientific and engineering aspects. In the past, such experiments have been carried out in drop towers, rocket missions and space stations. In the few existing drop towers in the world, experiments in free fall are carried out inside vacuum tubes. The air density inside the drop tube determines the turbulent flow around the falling object as well as the resulting air drag and the related reduced accuracy with respect to the residual acceleration during the experiment. Since the capacity of the vacuum tubes is extremely high, vacuum quality is mostly limited in the economic sense. Moreover, the weld seams on conventional drop tower vacuum tubes are causing, due to their required rigid steel structure, increased magnetic disturbances which can have a negative impact especially in high-precision tests.

In 2004, the Center of Applied Space Technology and Microgravity (ZARM) in Bremen has integrated a catapult into its drop tower to extend the experiment's flight duration under microgravity in the vacuum tube of 110 m height. By this means, the free-fall time can be extended from approx. 4.7 s to 9.3 s. Nevertheless, just three experiments per day can be conducted, since the complex evacuation of the whole vacuum tube is independent of the flight duration. In addition, the maximum allowable weight of the experiment is limited by the catapult. In catapult mode, experiments are limited to a total mass of 400 kg. Many experiments are not practicable due to this restriction. Furthermore, the experiments are also considerably limited in their physical dimensions. Just an inner length of up to 1.7 m and a diameter of 700 mm is the space available for the experiments [3].

1.1 THE CONCEPT OF THE EINSTEIN-ELEVATOR

The concept of the Einstein-Elevator presented in this paper is to accelerate an evacuable gondola carrying the experiment to 20 m/s by means of a linear direct drive and to let it describe hereafter a vertical parabolic flight of totally 4 s over a distance of 20 m. The same linear direct drive then decelerates the gondola's parabolic flight. Air drag and other parameters influencing the experiment are precisely compensated by the linear direct drive. Compared to the aforementioned drop towers, the innovative drive and guide concept of the Einstein-Elevator has a lot of advantages, like for example a repetition rate of up to 100 experiments per day due to the low vacuum volume to be evacuated as well as a higher payload of 1000 kg going along with an improved accuracy under microgravity ($< 10^{-6}$ g). The structure of the Einstein-Elevator's main components is shown in Fig. 1.

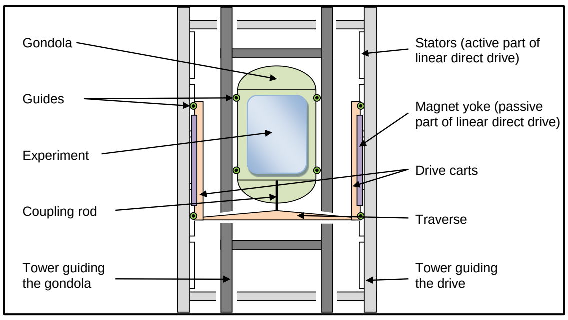

Fig. 1: Schematic diagram of the Einstein-Elevator

Fig. 1 shows an experiment inside a gondola which can be evacuated, as required. Together with the experiment, the gondola describes a vertical parabolic flight trajectory and is guided along the inner tower. The gondola is driven via two drive carts running on either side and holding magnet yokes, the passive parts of a linear direct drive. The left and the right drive cart are connected with each other by means of a traverse below the gondola, transmitting the driving forces via coupling rod to the gondola and the experiment. The stators, i.e. the active parts of the linear direct drive, mounted on the outer tower guiding the drive, generate the power required to accelerate the gondola together with the experiment up to the speed needed to perform the vertical short-distance parabolic flight. The specifically monitored and fixed experiment is able to levitate inside the gondola during the parabolic flight.

There is a wide range of applications under microgravity. Atoms and states of atoms are investigated for example in physical experiments. Here the gravity's masking effect has a negative impact on the test results and even makes it sometimes impossible to observe certain phenomena. Further fields of application are for example technical combustion, fluid dynamics, process engineering, materials sciences as well as biology and biomedical engineering, just to mention a few of them.

The Einstein-Elevator is the prototype of a new category of free-fall simulators. The overall system consists of subcomponents from different areas of plant engineering. These are for example components used in machine tools and elevator technology as well as drive systems as applied in modern roller coasters. The prototype that is based on an innovative and worldwide unprecedented drive and guide concept has been developed in a joint project of various university institutes from the disciplines mechanical engineering, electrical engineering and physics.

1.2 GENERAL REQUIREMENTS

To carry out fundamental physical experiments under microgravity in a reasonable manner from the scientific and economic point of view, a duration of microgravity of several seconds is necessary. The maximum technically feasible duration has been compared to the expenses related to the height of the elevator. A **duration of microgravity of four seconds** has been identified as an economically favorable basis for designing earthbound experiments. It corresponds to a net parabolic flight distance of 40 m (in total two times 20 m flight distance). The resulting total tower height of **less than forty meters** is quite small (including acceleration and deceleration distance plus safety zones at the top and bottom of the elevator). The costs for the elevator are manageable, too. Moreover, it does not have to face the disadvantages existing drop towers have to cope with, like for example long evacuation times to generate a vacuum. Therefore, **repetition rates of 100 experiments per day** can be achieved here. Due to the large number of experiments, it will be possible to achieve statistically significant experimental results within reasonable testing times. Besides the duration of the tests and the repetition rate, the allowable **payload of one ton** plays a decisive role for the large-scale facility's design. The most important parameter for carrying out experiments under microgravity conditions is, however, the residual acceleration generated during free fall. It is a decisive criterion for the quality of the experiments. Set to a **millionth of gravity acceleration (10^{-6} g)**, the residual acceleration of the Einstein-Elevator will be at least comparable to similar equipments [2].

2 SPECIFICATIONS

The specifications given below are mandatory for executing the experiments described:

- Duration of microgravity: 2 s in controlled free-fall mode, 4 s in controlled parabolic flight mode
- Dimensions of payload: $\leq$ 1.7 m diameter x $\leq$ 2.0 m in height
- Mass of payload: $\leq$ 1000 kg
- Residual acceleration in free-fall mode: < 10^{-6} g (target parameter)
- Rotation rate in free-fall mode: $\leq$ 0.006 /s
- Residual magnetic field around payload: < geomagnetic field strength
- Optional acceleration profiles: 0-1 g for at least 4 s, 1-5 g for at least 0.5 s
- Atmosphere in gondola: standard atmosphere, vacuum or inert gas of various pressure levels

- Atmosphere around experiment: standard atmosphere, vacuum or inert gas of various pressure levels

These specifications are identical for all experiments conducted in the projects described. The Einstein-Elevator's system properties, which are in compliance with the aforementioned specifications, are given in the following sections.

3 THE LARGE-SCALE FACILITY'S STRUCTURE

The concept of the Einstein-Elevator has been developed in a joint project of the following institutes: *Institute of Quantum Optics (IQO)*, *Institute of Transport and Automation Technology (ITA)*, *Institute for Drive Systems and Power Electronics (IAL)*. The structural concept of the facility is presented and described in the following sections.

3.1 COMPONENTS' STRUCTURE AND ARRANGEMENT

The very low maximum allowable residual accelerations of 10^{-6} g require equipment components on a very high precision level. Therefore, the structure has been optimized by using high-stiffness support structures to avoid vibrations and by separating vibration-inducing actuators from the vibration-sensitive testing environment. The drive as well as the guides of the gondola are prone to induce vibrations. Since the drive is considered to be most critical, drive and gondola are decoupled in order to avoid vibrations. The support structures are therefore designed as two independent units: one inner tower guiding the gondola and one outer tower guiding the drive. The total height of both towers is about 36 m. The required stiffness of the two steel structures is achieved by thick-wall tubes in the bottom part and thin-wall tubes in the upper part of the lattice construction. Besides an optimum weight distribution, the desired eigen frequency of > 4 Hz of the tower guiding the gondola can thus be achieved. Guide rails for the roller guides are fixed to both towers to guarantee a low-vibration guidance of drive cart and gondola. Adjustments can be made at intervals of one meter. The *roller guides* are explained in detail in Section 3.5. The basic components' arrangement is presented in Fig. 2.

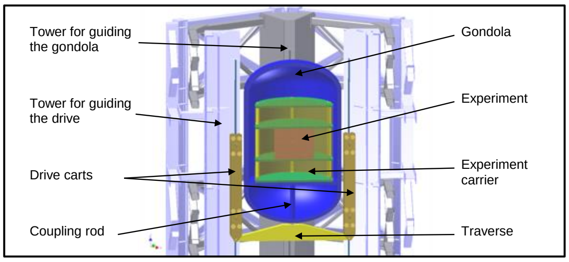

Fig. 2: Vertical cut through the Einstein-Elevator [1]

A vertical cut through the Einstein-Elevator's tower-in-tower construction showing the drive and guide concept is presented in Fig. 2. The components *gondola*, *experiment, experiment carrier, towers guiding drive and gondola, coupling rod and traverse* are highlighted in color and are described below. The experiment, i.e. the payload, is placed on an experiment carrier inside the gondola. A vacuum can be generated inside the gondola to reduce negative effects on the residual acceleration between the interior of the gondola and the experiment during the test. Two drive carts connected with each other by means of a traverse accelerate the gondola along the outer tower. Gondola and traverse are mechanically connected by means of a coupling rod. Due to this mechanical decoupling, disturbing torques and lateral loads transmitted by the drive to the gondola and thus to the experiment can largely be avoided. The coupling rod is simply supported on both ends, thus transmitting force merely in vertical direction. The gondola is guided on three rails in vertical and lateral direction along the inner tower. In contrast, each drive cart has its own two guide rails, as can be seen in Fig. 3.

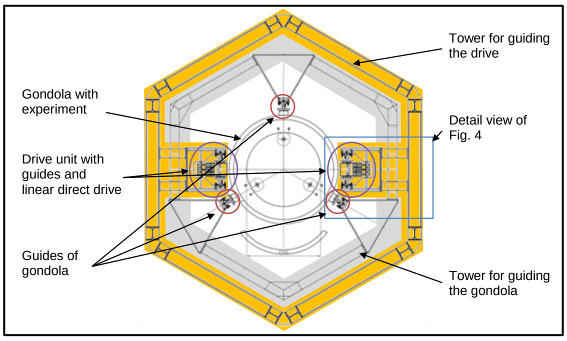

Fig. 3: Arrangement of guides (horizontal cut through the towers)

Fig. 3 shows a cross-sectional view of the towers and the gondola. The two towers are highlighted in color. Each drive cart (on the left and right side) has its own roller guides. While the drive carts are facing each other, the three gondola guides are shifted by 120°. The detail view, which is highlighted in Fig. 4, shows the main elements of the drive as well as of the towers guiding the gondola and the drive.

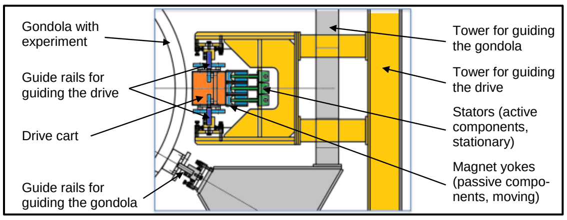

Fig 4: Detail view of drive and guide systems

The magnet yokes, i.e. the passive parts of the linear direct drive, are fixed to the drive carts, one of which is presented in Fig. 4. Supplied by frequency converters, the stators fixed to the tower generate controlled thrust. The magnet yokes are arranged as to minimize magnetic leakage fields and to prevent the partly supersensitive experiments from being disturbed.

3.2 TEST ENVIRONMENT

To avoid undesirable interactions between the two towers, they are erected on separate ring wall pile foundations. Fig. 5 shows the arrangement of the pile foundations.

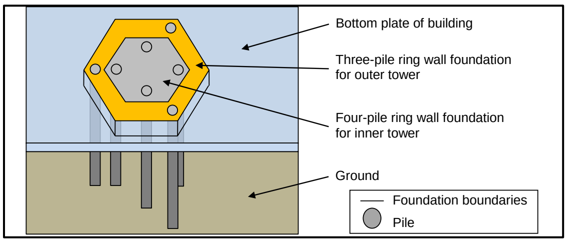

Fig. 5: Schematic of the Einstein-Elevator's foundation, indicating arrangement and shape of the ring wall foundations of the two towers (source: ITA and EHS)

The two towers of the Einstein-Elevator are erected on two separate ring wall foundations, supported by piles driven 12 m into the ground (Fig. 5). In this way, the slope stability, which is necessary for a safe execution of the tests, can be guaranteed. There is neither a connection between the two towers, nor to the building or the surrounding stairs. Moreover, the building envelope is founded on an individual shallow foundation, thus minimizing environmental influences on the test facility.

Besides dynamic environmental stresses, like temperature changes, solar radiation and ground water level, the Coriolis force also plays an important role when designing the guide systems. If the guides are exactly aligned and the experiment carrier moves ideally perpendicular to the gondola's bottom, there is a horizontal deflection of 4.796 mm westwards of the carrier's position due to the Coriolis effect. Each change of direction during the release of gondola and experiment can provoke in free fall a collision between the two of them and damage the experiment or the elevator. The safety of experiment and elevator therefore depends on the alignment of the two towers towards each other as well as on the vertical adjustment of the tower with the gondola's guide system. For a precise alignment of the two towers towards each other and with the envelope of the building so-called aligner stations are installed on the reinforced-concrete foundations (Fig. 6).

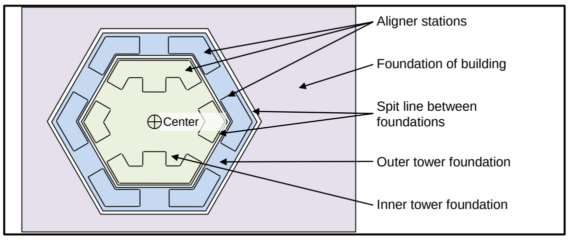

Fig. 6: Aligner stations for a precise alignment of the towers

The aligner stations of the two towers at the bottom between base frame and foundation are designed in accordance with the building's architecture. All dimensions of building and towers are related to the center of the floor space that is reserved for subsequent alignments.

A sudden relief of residual stress during the erection of the steel construction can provoke that tower or gondola move towards the experiment during testing, causing undesired collisions between gondola and experiment, jammed guides and damages to guides or other components of the elevator. To eliminate such residual stress, the towers are relieved of vibratory stress before being erected. With respect to statics and structural dynamics, this is possible without affecting the surrounding building parts due to separate foundations of the elevator and the rest of the building.

3.3 DRIVE

The drive is one of the most important component for the realization of this concept. As specified by the operational profile, the total mass of payload, gondola and drive cart of almost 2.7 t has to be accelerated to 20 m/s within 0.5 s in vertical direction for a distance of 5 m. The ideal profile as well as the force vs. time diagram is shown in Fig. 7.

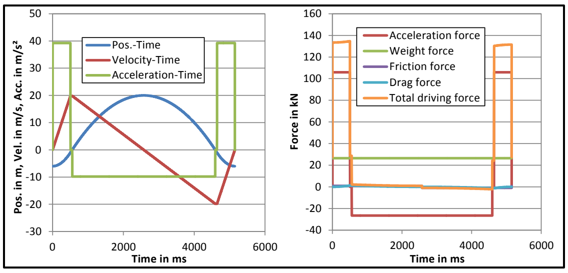

Fig. 7: Left: distance, speed and acceleration vs. time diagram, right: force required to realize the operational profile

The acceleration distance of 5 m is kept as short as possible to avoid cost-intensive tower structures and save construction height. The speed of 20 m/s is necessary to reach the initial speed that is required to perform the vertical parabolic flight over a distance of 20 m and 4 s microgravity, as shown in Fig. 7. Due to the large masses and the short acceleration distance, a mechanical power of 2.66 MW is needed to maintain the ideal operational profile. Efficiencies and losses of all components (cf. Fig. 8) have to be taken into consideration, too.

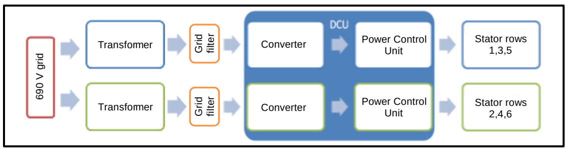

Fig. 8: Arrangement of drive components

As can be seen in Fig. 8, a medium-voltage 690 V grid supplies two 12-pulse (three-winding) transformers with 2300 A each. They are followed by circuit breakers and grid filter elements. The filters are needed to keep possible interactions between converter and 690 V grid within the tolerances specified in the respective DIN standard and to avoid negative effects of the experiments carried out in the Einstein-Elevator on the surrounding laboratory buildings, which are supplied by the same 690 V grid. Each transformer with subsequent grid filter is allocated to one of the two converters. Each converter is composed of four 355 kW converters. The converters and the other motor components are controlled via the drive control unit (DCU), being the higher-level system control. As specified by the DCU, the converters supply the power control units (PCU) which distribute the currents among the single stators. To transmit the large forces needed during acceleration, six rows of stators are required that are equally distributed among the two drive carts facing each other. The small forces needed in the free-fall mode to compensate air drag and rolling resistances can be generated by two rows of stators. For this reason, the middle row of the stators on either side is each continued along the complete length of the tower structure.

The stators, which are fixed to the outer tower, are connected via cable lines laid along the tower that guides the drive. Cabling starts from the bottom of the tower. Due to the high electrical power needed, large diameter cables are used, and a stress-relieved suspension at the interface between the tower that guides the drive and adjacent buildings is provided.

The higher-level system control monitors the DCU, specifying the mode of operation and releasing its execution. As a standard experiment, the aforementioned operational profile with 5 m acceleration distance over 20 m in free fall is selected. The parameters are matching the maximum demands on the drives. Beyond that, some experiments require other operational profiles. For example for experiments under increased gravity, initial accelerations of 1-5 g are of great interest. For such experiments, the subsequent free-fall phase is irrelevant. Experiments of 0-1 g are also carried out to simulate reduced gravity conditions, as for example known from the Mars or the Moon. Besides profile selection, the system control also performs safety monitoring measures, like the automatic control of the safety components before launching the experiment and the door lock during operation to avoid access to the test area.

Besides safety monitoring, a system to decelerate the gondola in case of a failure is provided, too. The worst case scenario is a power failure at the end of the free-fall phase. In this phase, the gondola has a maximum speed of 20 m/s. In case of such a failure, the gondola is decelerated by three braking systems arranged in series. In case of a failure, the stators of the linear direct drive are first of all short-circuited, serving as eddy-current brake. Beyond the desired braking zone, accompanying iron swords are plunging into the magnet yokes that are arranged in parallel to the stators. Together, they act as a highly efficient eddy-current brake. The low residual speed is absorbed by flexible rests and a hydraulic cylinder.

3.4 POSITION TRANSDUCERS

The standard linear direct drive used here relies on Hall effect sensors for speed detection, rendering a relatively rough scaling of 8.3 cm. This is not sufficient for a precise control of the Einstein-Elevator. Therefore, two supplementary position transducers are required, i.e. one for each drive cart. The great challenge is to maintain an accuracy of 1 mm over the complete distance and a sample rate of the drive control > 10 kHz. In addition to the electrical properties, temperature stability of the measured values and a critical consideration of the thermal expansion due to varying temperatures along the test route are taken into consideration when designing and selecting a position transducer. Possible transducers are for example tailor-made glass scales with adapted sensor head and modified instrumentation suitable for detecting speeds of 20 m/s.

3.5 ROLLER GUIDES

With respect to the system properties, the guiding system is another decisive factor to be considered in the Einstein-Elevator. The magnitude of the maximum occurring residual acceleration depends to a large extent on the guide parameters. By providing separate guides for drive and gondola, the drive's disturbing effects are decoupled from the gondola. Different types of guides have been tested to keep vibrations low that are induced by the guides themselves. Magnetic, air and plain bearings as well as roller guides have been tested. With respect to the high dynamics required here, the use of air bearings is not suitable due to limited stiffness. Plain bearings are also insufficient for this application due to limited capacity. With respect to the high speeds of 20 m/s, only magnetic and roller guides come into consideration. Magnetic guides have the disadvantage that there exists no standard product on the market, which suits this type of application. On the other hand, it is not feasible to develop a new system for use in the Einstein-Elevator.

Roller guides are applied in high-speed elevators with speeds up to 16.8 m/s and in roller coasters with speeds far beyond 30 m/s. The combination of high speeds and high accelerations of up to five times the acceleration of gravity as well as the high demands with respect to vibrations, comparable to those of machine tools, have been the decisive factors for selecting roller guides.

The rollers for guiding the drive cart can be designed depending on the forces generated, while the guides for the gondola are designed towards high precision. The two drive carts are guided on four points. So each cart can be moved independently on its two guide rails. The gondola is diametrically guided on three rails in triangular arrangement. The arrangement of the two guides is presented in Fig. 10 and Fig. 11.

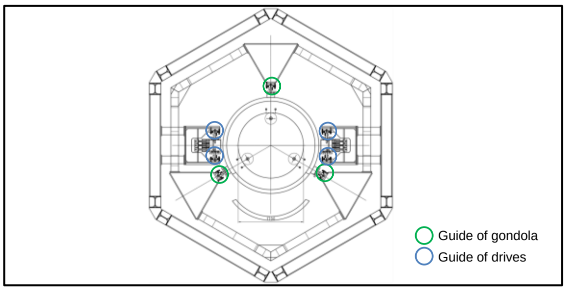

Fig. 10: Top view of tower-in-tower structure with gondola, drives and guides

As described in Section 3.1 “Components' Structure and Arrangement“, the guides for the drive and the gondola are fixed to separate towers. The inner tower shown in Fig. 10 supports the drive on four rails fixed on two sides of the structure. For guiding the gondola, three guide rails are diametrically attached to the outer tower. Fig. 11 shows a cross-sectional view of gondola, drive carts and traverse.

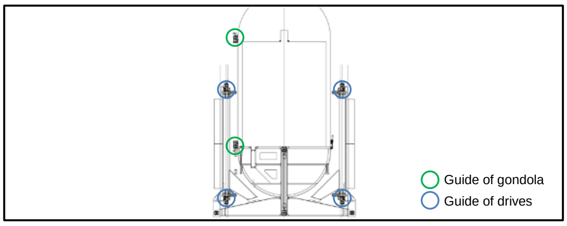

Fig. 11: Vertical cut through gondola with guides for gondola, drive carts and drives

For the configuration shown in Fig. 10 and Fig. 11, the rollers' low-vibration behavior has been tested in advance on a roller test rig considering the high occurring speeds and a smooth running. The test rig (cf. Fig. 12) has two fixtures holding the rollers under test.

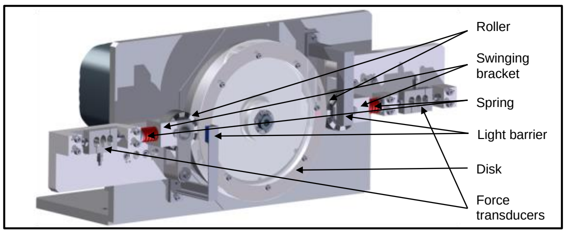

Fig. 12: Roller test rig with two fixtures holding the rollers under test

On the roller test rig, vibrations are analyzed that are induced by the rollers moving on the disk. Force transducers were added to the test setup; otherwise the setup with spring and swinging bracket is the same as in the final setup used in the Einstein-Elevator. The roller movements can be monitored by light barriers. For the investigated material combination and a preload force of 2 kN, there is no slip first. The output signals of the force transducers can be used for further evaluations from which conclusions can be drawn concerning the induced vibrations. The first evaluation of a test series with five identical test runs is shown in Fig. 13.

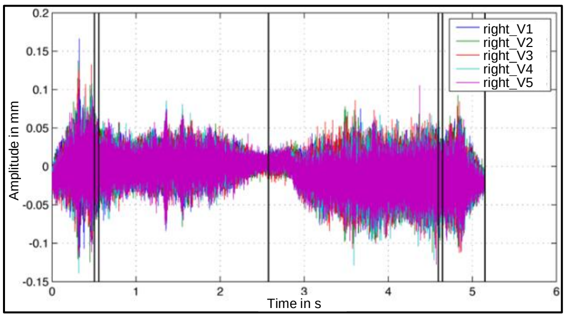

Fig. 13: Vibrations of roller guides measured on the roller test rig

The latest material combination, a standard roller and a hardened disk or rail, leads to vibration amplitudes of max. 0.15 mm. The vibrations measured can be implemented in an existing multi-body model [1]. Based on this model, possible vibrations can be predicted for the three main components. The accelerations in the xy plane determined by simulation are plotted for the experiment in the diagram below.

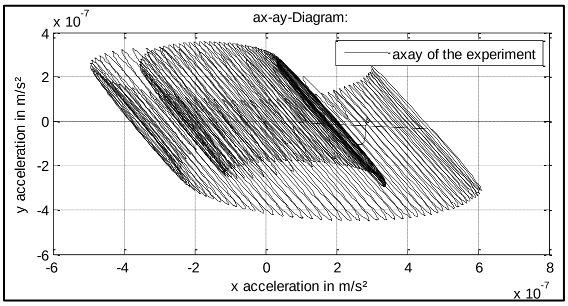

Fig. 14: Vibrations determined based on a simulation model [1]

The low-vibration execution of the later tests in the Einstein-Elevator is investigated based on this simulation model. Different rail materials in combination with different types of rollers of various manufacturers are presently being tested. First test results show that conventional roller guides perfectly comply with the maximum occurring residual acceleration of $< 10^{-6}$ g, considering the aforementioned precision with respect to component selection and manufacturing.

3.6 DRIVE CARTS

The load generated by the linear direct drive is transmitted between the separately moving drive carts via traverse and coupling rod to the gondola. Each drive cart carries three pairs of magnet yokes that are arranged in parallel. Each magnet yoke has a length of one meter, amounting to six meters of stators for each drive cart. The carts are each guided on twelve pre-stressed rollers (two times three on top and two times three at the bottom). The traverse is floating bearing mounted to one cart and fixed bearing mounted to the second cart (cf. Fig. 15).

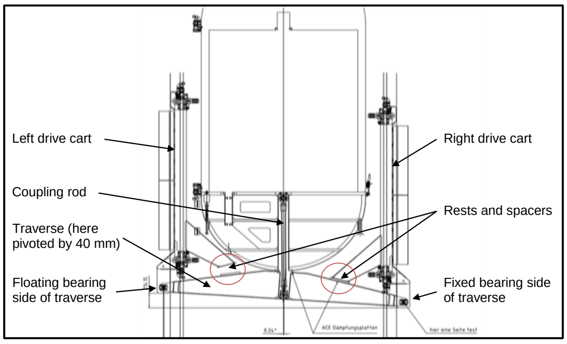

Fig. 15: Traverse attachment between the two drive carts

The arrangement shown in Fig. 15 tolerates slight positional deviations without jamming of the carts. Moreover, a dead stop connects one of the two carts firmly to the traverse in case of a height difference of 40 mm between the two drive carts. In case of a malfunction, rests covered with damping plates prevent the structure from being distorted, if the spacers touch the traverse.

3.7 GONDOLA

As described in Section 3.5 “Roller Guides“, the gondola is guided on three sides. An experiment carrier with a maximum height of 2000 mm and a diameter of 1700 mm can be placed inside the gondola. The experiment is integrated into the gondola in the integration area. An automatic centering unit places the experiment in its initial position in the center of the gondola. The centering unit as well as the safety pin attached on top of the payload is shown in Fig. 16.

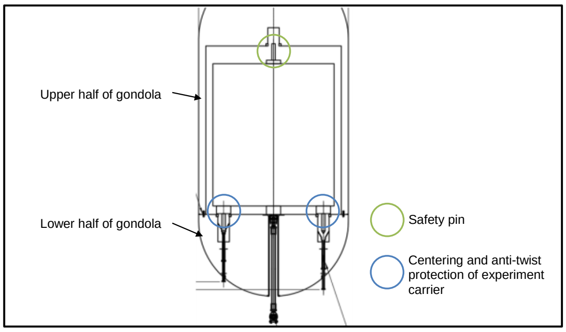

Fig. 16: Centering and anti-twist protection of the experiment carrier

As described above, off-center load can be avoided during the acceleration and deceleration of the experiment. Lateral deviations can be limited, too. Centering is also a safety measure protecting against excessive distortion during the test. In combination with the safety pin, the experiment is prevented from colliding with the outer shell of the gondola caused by excessively large movements in horizontal direction.

Prior to testing, the upper and lower half of the gondola is connected by means of fasteners. Inside the gondola, the air can be exhausted to avoid air drag around the experiment. The desired vacuum quality is set to $< 10^{-2}$ mbar provided by two subsequent vacuum pumps. In Fig. 17, the aforementioned two-stage vacuum pump is shown.

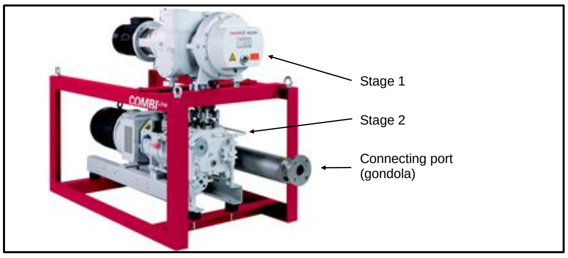

Fig. 17: Two-stage vacuum pump

With a vacuum quality of $< 10^{-2}$ mbar, the air drag inside the gondola is low enough not to exceed the maximum occurring residual accelerations of $< 10^{-6}$ g.

Besides a connecting port for the vacuum pump, all electric connections are provided that are needed for battery charge inside gondola and payload, for data download after test completion and for telemetric data transfer out of the electromagnetically shielded gondola.

Since the drive carts, the traverse, the coupling rod and the gondola are exposed to high loads during the acceleration of the experiment, the mechanically stressed components are simulated, analyzed and adapted by means of Finite Element Methods (FEM). In addition to the gondola's and the drive carts' stiffness, the influence of aerodynamics on the moving components is investigated in advance. The simulation results of the air flow achieved for a test run with 20 m/s are presented in Fig. 18.

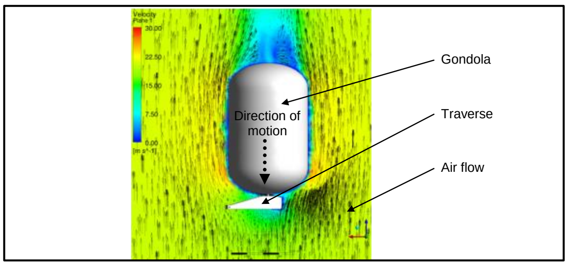

Fig. 18: First aerodynamic simulation results of gondola and traverse

To design the mechanical components, the avoidance of air blasts caused by the gondola moving past the horizontal elements of the towers has to be analyzed. These air blasts can induce vibrations in the gondola shell, potentially transmitting structure-borne noise to the sensitive experiment and thus harming it.

3.8 EXPERIMENT CARRIER

Independent of payload and experimental set-up, a standard experiment carrier is used. The experiment carrier is a platform on which the experiments are mounted. It has a total height of 2000 mm and a diameter of 1700 mm. The mass of experiment carrier, infrastructure and experiment is limited to 1000 kg. Next to the experiment, a computer with internal power supply is integrated into the experiment carrier for recording and monitoring the experiments. The power supply is battery-buffered during testing. In park position, an automatic coupling between experiment carrier and gondola as well as a manual coupling between gondola and the tower's general power supply is provided, and the battery is recharged. When the gondola is in park position, test data can either be transmitted in real time or staggered in time in case of electromagnetically sensitive experiments. The sampled data are transmitted to the control station for further processing by the experimenters.

4 BUILDING REQUIREMENTS

To meet the required accuracies, the demands made on the building are very high, too. This concerns for example the separate pile foundations ensuring the elevator's slope stability and vibration protection of the high-sensitive experiments carried out in the HITec research facility. Moreover, high temperature stability has to be achieved on site to be able to maintain the guiding accuracy. These requirements have already been considered during the design phase of the tower shell.

4.1 CONFIGURATION PROPOSALS

The Einstein-Elevator is situated in an exposed position in the new HITec (Hannover Institute of Technology) facility. The laboratories are accommodated in the front part of the building (Fig. 19). The tower of the Einstein-Elevator is set out of line at the rear of the building (Fig. 20). Inside the tower, two towers are deeply anchored into the grounds. The upper edge of the pile foundation is approx. 10 m below ground line. The control station monitoring the Einstein-Elevator, experiments and the test preparation premises is on the basement floor. So the experiments can be prepared in the integration area and finally brought directly into the elevator without any stairs or steps in between.

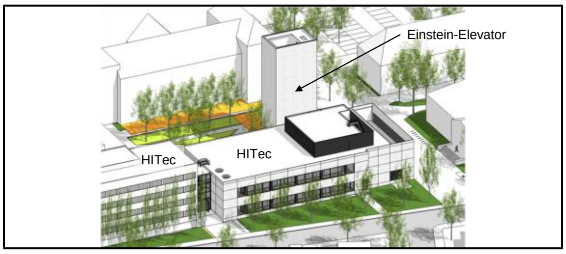

Fig. 19: Existing HITec facility (left), new facility (middle) and Einstein-Elevator's tower (source: Carpus+Partner)

The existing HITec facility (Fig. 19, in the front) accommodates 25 temperature and vibration isolated laboratories, serving for fundamental research work necessary to carry out the experiments in the Einstein-Elevator. The Einstein-Elevator is situated in second line surrounded by various university institutes. The HITec laboratory complex and the tower are presented in Fig. 20.

Fig. 20: Rear view of new HITec building and cut through the Einstein-Elevator's tower (source: Carpus+Partner and ITA)

The Einstein-Elevator's tower has a height of just under 30 m above ground line. Its massive outer shell is a reinforced concrete structure preventing environmental influences like temperatures varying throughout the day and wind loads from affecting the test conditions.

In addition, the Einstein-Elevator is situated, together with other premises needed for carrying out the experiments, in a separate part of the building. The floor plan as well as the tower's interior is shown in Fig. 21.

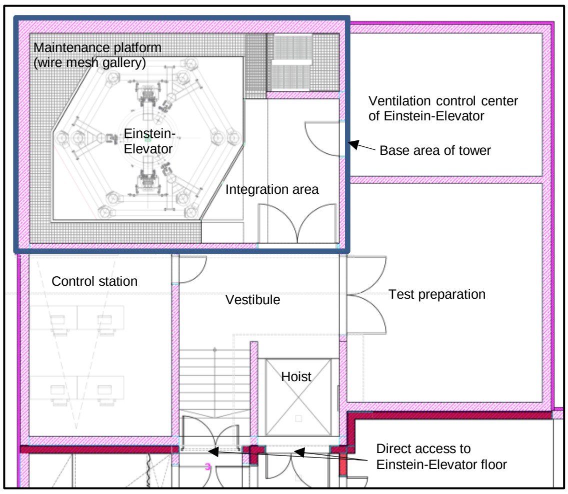

Fig. 21: 1st basement floor plan and top view on installation surface and wire mesh gallery around the Einstein-Elevator

The Einstein-Elevator is positioned inside in the center of the tower shell. Platforms of about 80 cm width are inserted at distances of approx. 2.30 m necessary for adjustment and maintenance work. Fig. 22 shows the maintenance platforms as well as the floor plan for further drive components and air-conditioning units.

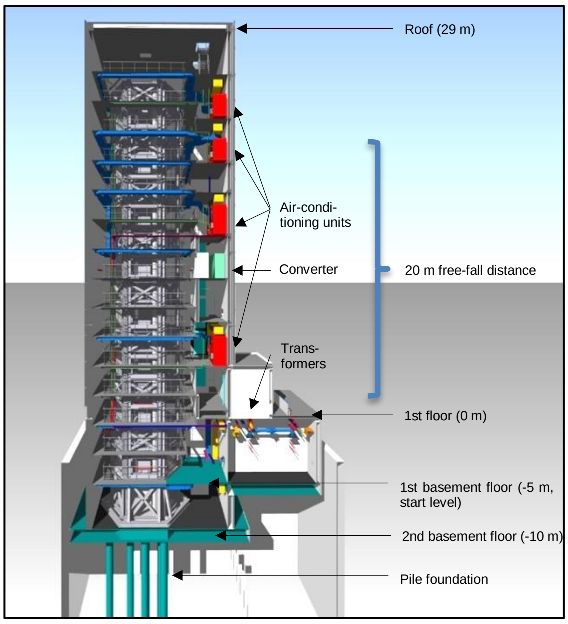

Fig. 22: Side view of tower-in-tower construction with arrangement of air-conditioning units and rooms for transformers and converters

To maintain the temperatures along the towers constant, the tower is flooded with preconditioned air. A temperature gradient in horizontal direction has to be avoided to protect the towers from being distorted, as this could provoke an undesired deviation of the experiment's trajectory in the gondola. Although a layering of differing air temperatures in vertical direction cannot be avoided, it is not disadvantageous due to the symmetric tower construction. To reduce vertical air stratification, preconditioned air is blown into four inlets arranged in a circle around the tower.

If guide rails still happen to be misaligned, it has to be possible to make easy readjustments from any place. For this purpose, an operating platform is lowered from the top level by an overhead crane. The operating platform is shown in Fig. 23.

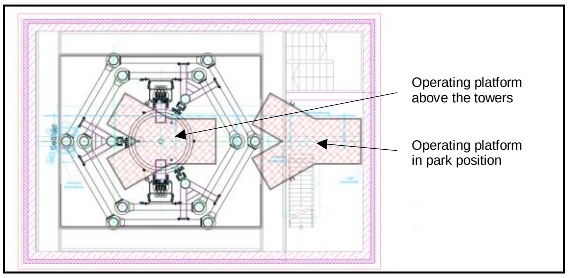

Fig. 23: Operating platform for adjusting the guide rails

As indicated in Fig. 23, the operating platform is lowered from its centered park position on the top level above the towers. The operating platform can be arrested on the very level, where work is necessary, and is accessible via a wire mesh gallery mounted to the tower.

4.2 TEST PREPARATION

On the basement floor, which is the Einstein-Elevator's integration area, one room is provided for preparing the experimental setup. It is equipped with two workplaces (cf. Fig. 24).

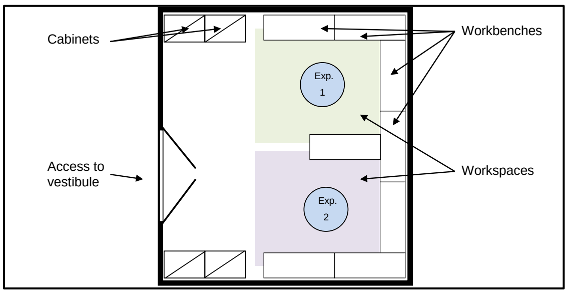

Fig. 24: Simultaneous test preparation for two experiments

The workplaces are air-conditioned and equipped with workbenches, each place being provided with pressurized air, cooling water, manufactured gas and various electrical connections. Staying on the same level, the prepared experiments are then brought via a vestibule into the Einstein-Elevator.

4.3 CONTROL STATION

The experiments are monitored from the control station, which is equipped with four workplaces (cf. Fig. 25).

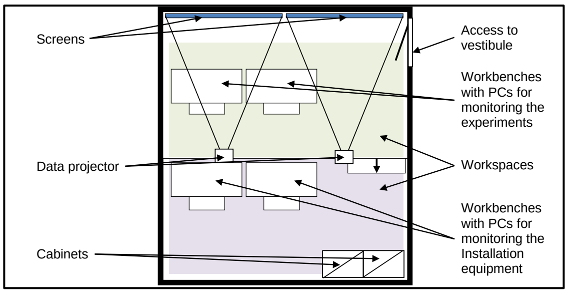

Fig. 25: Einstein-Elevator's control station with four workplaces

Two workplaces are required for permanent operating staff and two are reserved for researchers setting up the experiments. Live videos from the tower and system states displayed on monitors or by data projectors are visualized for all operators. The safety during a test run is also monitored via the control station. It is checked for example, whether the tower has been left, whether all entrances to the Einstein-Elevator are locked, and whether all systems have been started properly.

5 CONCLUSION

The novel concept of the Einstein-Elevator, that is unprecedented worldwide, is a modification of the classical drop tower. It is suitable for conducting experiments under microgravity up to 4 s with a payload of one ton and a repetition rate of 100 experiments per day. The innovative research facility enables research work on most varied topics, ranging from experiments in the field of fundamental physical research studies towards practice-oriented applications in the field of mechanical engineering. High-precision experiments require the maintenance of a maximum tolerable residual acceleration of $< 10^{-6}$ g in the test setup during free fall. This is related to the experiment which is mounted on the experiment carrier. The resulting demands on tower structure, drive, roller guides and control equipment are thoroughly considered in preliminary research work. The developed setup is a tower-in-tower construction, enabling the mechanical separation of drive and gondola. Vibrations induced by the drive do not affect the sensitive experiments, so that the maximum residual acceleration of < 10^{-6} g can be maintained.

The drive's six rows of stators generate the mechanically necessary overall power of 2.66 MW. The drive is divided into two independent systems, each accelerating one of the two drive carts moving on either side. Each cart is separately equipped with position transducers to control the drive units. The carts are guided by roller guides on two rails each.

As it is necessary to keep vibrations low, the roller guides belong to the most critical components. For this reason, a specific low-vibration arrangement has been developed. Moreover, preliminary research on various roller-rail combinations has been made. The test results can be implemented in an existing mechanical simulation model to be able to predict vibrations that might occur during an experiment. Besides the mechanical excitation of drive and rollers, aerodynamic effects can be analyzed, too.

In addition to the air-conditioned elevator's envelope erected on slope stability foundations, the HITec facility also disposes of all infrastructures, including test preparation premises and control station necessary to carry out the experiments. The construction time is scheduled for September 2014 to December 2016.

6 REFERENCES

[1] Lotz, C.; Overmeyer, L.: „Mechanische Ersatzmodelle zum Nachweis der Realisierbarkeit minimaler Restbeschleunigungen während der Freifallphase im Einstein-Elevator“, 9. Fachkolloquium der Wissenschaftlichen Gesellschaft für Technische Logistik e.V. (WGTL), Dortmund: Verlag Praxiswissen, pp. 199-208, September 2013,
DOI: 10.2195/lj_Proc_lotz_de_201310_01.

[2] Lotz, C.: „Schwerelos in Hannover“, phi – Produktionstechnik Hannover informiert, Hannover, 2013, ISSN 1616-2757.

[3] ZARM: „User Manual“, Drop Tower Operation and Service Company, ZARM FABmbH, Bremen, Version: April 26th, 2012.

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