Full-Scale CargoTube Demonstrator based on Hyperloop Technologies

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Abstract.

CargoTube is a technological solution for transporting goods in a low-pressure tube with significantly reduced frictional resistance and minimal energy input. CargoTube is based on hyperloop technology and focuses not only on the development of the system technology, consisting of tube, guiding system and transport vehicle, but also on intermodality with other modes of transport. Freight handling plays an essential role in the efficiency and cost-effectiveness of the CargoTube system [1].
To investigate this innovative transport system, a full-scale demonstration facility with a steel tube 26 m long and 1.7 m in diameter and adapted vacuum technology is being built. The demonstrator will be used to compare different drive concepts such as linear motors or an integrated drive system within a low-pressure tube. Airlock technologies are to be developed and evaluated to enable a high throughput of the cargo. Possible technology solutions are the discharge of the pods in a segmented unloading chamber or the docking to the vehicle inside the tube via lateral pressure locks. In a further research step, concepts are developed that enable highly automated loading processes in logistics hubs.
The determined test data of all subsystems will be compared with simulation and modelling results to refine existing models and increase the accuracy of the simulations. This paves the way for extrapolation to a larger network with existing local supply chains as well as regional or national networks leading to an outlook for a European Hyperloop research infrastructure that enables research, development and certification processes.

Keywords: Hyperloop, CargoTube, transportation, infrastructure, demonstrator.

1 Introduction

New transport systems such as Hyperloop or CargoTube are track-guided systems that travel in a low-pressure environment inside a tube with low energy consumption and zero emissions [2]. The technical development of tube systems, vehicles, drives and operating procedures is currently being worked on worldwide. Individual components have already been built in the form of prototypes and must now be used in real test environments for the next stage of development. Knowledge gained in different test systems must be evaluated in order to transfer the innovative concept for passenger and freight transport based on Hyperloop technologies into a long-term coordinated transport system. The CargoTube concept transports goods in the size of standardized Euro pallets and Euro boxes, for which a tube diameter of slightly more than 1.6m is sufficient. A full-scale demonstrator for CargoTube is currently under construction and can generate relevant test results so that further development steps for this mode of transport are possible.

2 CargoTube concept

Today's freight transport volume in Europe is largely carried out on standardized Euro pallets or Euro boxes and had a volume of more than 13 million tons in 2020 [3]. The CargoTube concept focuses on the transport of goods in this magnitude in order to achieve a significant reduction of transport-initiated emissions. At the same time, the substitution of road or rail transports by in a relatively small tube up to diameters of 2m is easily realizable. This tube diameter allows a pod size to accommodate goods in pallet width with a flexible number of boxes lined up in the direction of travel. The number of boxes per pod must be determined by optimization and depends largely on the application of the system. In the case of an exclusive point-to-point connection, larger units (10 pallets) make sense; within a widespread network, smaller units (3-5 pallets) can also be bundled to enable order-related individual delivery. This size of tube requires little space and can be installed on stilts, at ground level or underground. In the case of above-ground installation, the required energy can be largely generated by the installation of solar modules. The speed is planned to be up to 300km/h to realize simple vehicle guidance systems. Wheel/rail combinations are currently the most cost-effective solution. The drive of the pods can be installed inside the vehicle or as a linear motor in the track.

3 Design of the CargoTube Demonstrator

To validate the CargoTube concept, a demonstrator is being developed and realize at Emden/Leer University of Applied Sciences. The aim is to create a test infrastructure that enables the implementation of CargoTube in a technology-neutral way. Technical solutions from other development teams can also be examined and validated. All test results are needed for further development stages up to the realization of a commercial transport system. The focus of the investigations is on the drive concept, the vacuum technology, the airlock system and the intra-logistics for loading and unloading the pods.

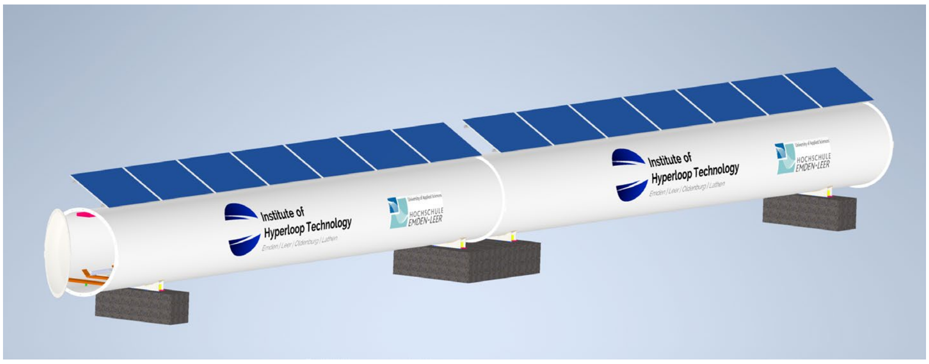

Fig. 1. Demonstrator with support structure and solar panels

3.1 Overall design

The tube size of the demonstrator is based on the standardized delivery sizes of the steel tube industry in order to keep costs to a minimum, even for commercial applications [4]. Suppliers currently supply standard tubes up to 1676mm (66inch) in diameter with wall thicknesses up to 25mm, which are sufficient for transporting standard pallets on a transport capsule. Since the pressure difference is a maximum of 0.1MPa, a standard wall thickness of 14.5mm is chosen. These tubes are sufficiently stiff to realize spans of 12m. The demonstrator is composed of 2 tube segments, each 13m long over flanges, and supported on three foundations as shown in Figure 1. The middle foundation point is designed in such a way that a slide valve or experimental structural components can be inserted between the pipes at a later stage. With that two individual chambers can be created, among other things. This can then be used to test the entry and exit transfer from the main tube under different pressure situations. Relevant factors here include ventilation and evacuation times, taking into account noise emissions and the formation of condensation.

Inside the tube, a track is realized by support beams in order to place and test different drive and guide systems, see Fig. 2 left. A wheel/rail system and a linear motor will be installed in order to carry out driving tests with the experimental vehicles for operational stability, see Fig. 2 right. These include acceleration and braking tests as well as investigations on the behaviour of system components under low-pressure conditions. This also includes monitoring the operating conditions of the vehicle and the tube.

For the operation of the demonstrator, a vacuum system is used which can reach pressure ranges of down to 0.1 kPa. In particular, the operating behaviour of vacuum chambers or networks of this magnitude is of scientific and economic interest for future CargoTube applications. Furthermore, the operating procedure is being developed to optimize the logistical processes inside and outside the tube and to prepare them for commercial applications.

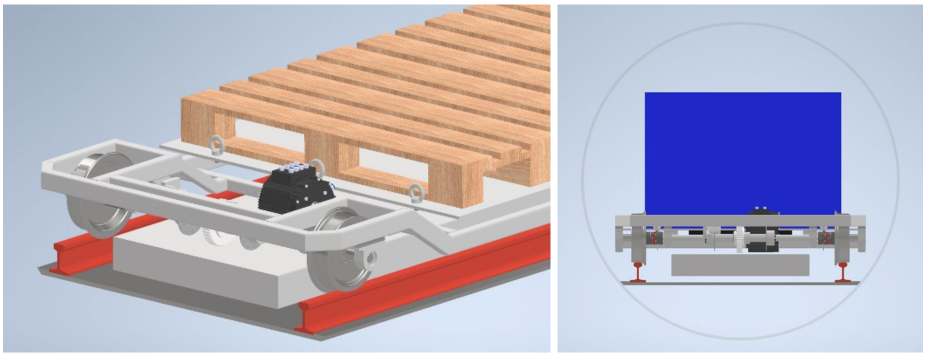

Fig. 2. Left: Self-propelled Pod platform (shell not shown) with electric engine and linear motor (schematic) between the tracks. Right: Cross section.

3.2 Motion concept

The full-scale CargoTube demonstrator investigates different drive systems for transporting goods while minimizing energy consumption. As CargoTube is designed for low speeds and the demonstrator initially only has a length of 26m, a vehicle concept for the wheel/rail system with its own drive is being built. The drive is provided by an axle-coupled electric motor with battery, see Figure 2 on the left. With this, relevant characteristic data for the operation of a self-propelled pod can be determined.
In a further equipment stage, a linear motor is installed in the track, whereby the guidance of the vehicles is still provided by the wheel/rail system, see Fig. 2 right. With this system, higher acceleration values and shorter braking distances can be achieved, so that the resulting loads can also be examined in relation to the goods. For both drive systems, the problem of limited heat transfer during operation in low pressure is also being investigated and possible solutions are evaluated.

3.3 Air locks and handling

The fast and automated handling of goods is an argument for CargoTube. At the ends of the demonstrator tube, a locking door is initially provided, which is swung out to the side or automatically moved upwards. This allows the first handling data to be determined, which describes the loading and unloading. After the chamber has been ventilated, the pod can be moved out of the system and the load exchange is automated. The logistics processes then take place behind the tube, which corresponds to a approach for a point-to-point connection, for example to supply an industrial site through a logistics hub.
In order to minimize lock times, the pod is to be loaded and unloaded inside the vacuum tube in a further expansion stage. In this case, the pod is in the position of a docking lock without having to be ventilated. The docking lock encloses the loading hatch so

that the automated loading processes can be carried out under normal pressure without ventilating the tube [5].
Handling and picking of the goods is to be automated. A Digital Twin is to be set up as part of development projects. With regard to the achievable cycle times of the lock technology used, an optimized solution can be generated by varying system elements from known automation elements (including robotics, autonomous vehicles and AI-supported pick-and-place solutions).

3.4 Vacuum system

The operation of the demonstrator and the subsequent economic operation of the transport network according to the CargoTube principle is also influenced by the vacuum system used. A system providing high volumetric gas flows leads to shorter cycle times. First of all, a vacuum must be created in the tube so that the movement of the vehicles can take place with minimal air friction resistance.
With the vacuum system installed, the pumping costs to generate the pressure level as well as to compensate for pressure losses during the locking process and for the expected leakage rates can be determined. An initial configuration is equipped with a rotary vane pump, which can realize the normal operation of a CargoTube system via a pipe system with different valves and flexible arrangement of various other components. The evacuation time and the aeration time of the 40m³ tube are set at 8 minutes each. Control and monitoring by means of a large number of sensors so that operating data is available for future system configurations.

4 Hyperloop research and certification infrastructure

Due to its technical equipment and dimensions, the full-scale CargoTube demonstrator is able to determine essential parameters for the design of a transport system based on the Hyperloop principle in a scientifically proven way. The data can be used for validation in simulation software, among other things, in order to carry out economic feasibility studies. Furthermore, the demonstrator is very flexible in its design, so that system components from other developers can also be examined in the test facility. Since the Emden/Leer University of Applied Sciences operates independently of manufacturers, the test facility can also be regarded as a certification facility.
Technical testing and also the approval of system components are essential for the later operation of CargoTube/Hyperloop systems. The first draft standards are already being prepared by the European Joint Technical Committee [6]. The experience gained with the full-scale demonstrator can form the basis for a large-scale test and certification facility.

5 Conclusion

In the full-scale CargoTube demonstrator, various investigations into the operating behaviour can be carried out with experimental vehicles for the transport of goods on Euro pallets and Euro boxes. In addition, the low-pressure test environment can be used to determine the system behaviour of all components, including those from external developers, for later commercial use. Data is obtained for use in simulations and set up of a Digital Twin.

The experience gained from this test environment can serve as the basis for a future international certification centre for Hyperloop applications, where continuous operation, driving in a loop and testing of various system components should be possible. After a homologation phase on this large-scale facility, commercial operation for CargoTube and Hyperloop systems could take place, thus making a significant contribution to the low-emission and sustainable transport of goods and people.

6 References

1. Neu, W. et al.. CargoTube: Next Generation Sustainable Transportation by Hyperloop Technologies. In: Kabashkin, I., Yatskiv, I., Prentkovskis, O. (eds) Reliability and Statistics in Transportation and Communication. RelStat 2022. Lecture Notes in Networks and Systems, vol 640. Springer, Cham. https://doi.org/10.1007/978-3-031-26655-3_26 (2023)
2. Motwani, S., Gupta, A.: Experiencing Hyperloops: The Transit of the Future. Computer. 54(7), 37–45. (2021)
3. DVZ: https://www.dvz.de/rubriken/logistik/detail/news/umschlag-von-geisterhand.html last accessed 2023/09/12
4. Mannesmann Homepage: https://www.mannesmann-grossrohr.com/fileadmin/footage/MEDIA/gesellschaften/szmgr/documents/MGR_Lieferprogramm_2017.pdf, last accessed 2023/09/18
5. Gerritse P., Xanthopoulos S.: Airlocks at a Hyperloop Station: A comparison of vacuum interface options, (Delft Hyperloop), EHW 2021 Research submission (2021)
6. CEN/CLC/TR 17912: A first step in the standardization of the European hyperloop industry; JTC 20 (Cen-CENELEC); published Document: CEN/CLC/TR 17912:2023 'Hyperloop systems - Standards Inventory and Roadmap' (2023)