Method for Calculating the Beam Span Structure During Motion of the Magnetic Levitation Transport

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Abstract. Magnetic levitation transport technology has great potential for implementation in the transport complex of Russia. Development of technical conditions and normative documentation is an integral step for the introduction of these innovations. This article proposes a computational model of a magnetic levitational train, which gives an idea of maglev train dynamic effect nature on bridge structures. The importance of this issue is due to the fact that in the construction of high-speed railways on overpasses is preferable to the ground version and the increase in construction costs caused by the need to strengthen the span structures for passing high-speed trains reduces the attractiveness of projects. Based on the results of calculations, conclusions about the significant difference in the nature of the transfer of loads from maglev trains to infrastructure in comparison with the conventional wheel-rail technology were made. Maglev trains allow to move at significantly higher speeds without a multiple increase in the dynamic ratio for bridge structures. The calculation model proposed in this article confirm the possibility of reducing costs for the transport infrastructure for magnetic levitation transport. The article outlines vectors of application and optimization of this model and draws conclusions about basic directions of further research in field of creation a regulatory and legal framework for this new type of transport in Russian conditions.

1. Introduction

Magnetic levitation transport technology has significant advantages and potential over traditional technology based on the contact "wheel-rail":

- Reduced depreciation of infrastructure [1,2];
- Increase of the speed range up to 600 km/h and more [3];
- Great potential to reduce energy consumption [4].

At the same time, the introduction of such a high-speed technology in Russia, a country with consolidated economic centers and large distances between them, would lead to a significant acceleration of the processes of creating value, increasing GDP and positive social effect [5,6]. So in China, a country with similar geographic characteristics have already realized these prospects and have outlined the tests of their maglev train, capable of speeds exceeding 600 km/h, for 2020 [7]
At the same time, it should be separately noted that the cost of constructing a transport infrastructure for a maglev: span structures and supports, is from 60 to 80% of the total cost of projects [8]. Therefore, in many respects, the commercial success of the project will depend on the complex of elements optimization studies.

In this article, which is based on the methodology of designing bridge structures for high-speed railways and the experience of operating magnetic levitation trains, an optimal design model for calculating beams for a magnetic levitation load is determined.

2. Statement of the problem of the calculation of span structures for magnetic levitation transport

For today, there is no actual Russian regulatory basis for maglev trains and facilities for them.

The design of man-made structures for magnetic levitation transport is a new task for Russian bridge constructors. This task requires a complex solution of the factors set which interact on artificial structures for maglev:

- A new way of transferring loads;
- The impact of high-frequency currents on the structure;
- Increase the speed range.

At the same time, the result of this complex research should be a set of constructive solutions, the main of which are:

- Determination of the cross-sectional shape;
- Determination of the optimal span length;
- Selection of single/continuous beam system;
- Determination of the parameters, type of abutments and supports;
- Justification of the foundations.

All these decisions must be taken in consideration of the multi-additive approach, which takes into account both the design requirements and the convenience of installation in a short construction period.

Considering the experience of the high speed railways construction, mainly described in [9,10] and the methodology for calculating the infrastructure of the magnetic levitation routes of Transrapid [8], it is possible to determine a factor that need of detailed study:

- Rigidity of the structure;
- Deflections of span structures;
- Centrifugal acceleration;
- Dynamic effects;
- The radius of the curves and the grade of the route;
- Displacement of the upper part of the supports;
- Wind load accounting;
- Aerodynamic impact;
- Consideration of vibration;
- Taking into account the seismic effect;
- Account of collision of vehicles with support of bridge;
- Collision of vehicles on the route.

In this case, the criterion for the first iteration of the selection of the parameters of the span structure is the satisfaction of the condition with respect to permissible displacement of the middle point of beam structure.

According to [11], the permissible value of this parameter for magnetic levitational train load are only 1/4000 of the span length, which is 5 times more than the requirements for bridges for conventional railway loading [9] and much greater than the tolerances of the Eurocode for high-speed trains - Figure 1.
Such a small value of the permissible displacements is explained by the need of minimization the influence generated by maglev train on the infrastructure during calculating the air gap between the active (track) and the passive (carriage) parts of the linear engine[12] - Figure 2.

The air gap is an important parameter of the vehicle and the efficiency of the linear motor. And the opportunity that appeared with the development of computer technology which gave the opportunity of high frequency calculating control this parameter and served in its time as an impetus to the development of technology. Today, on the Transrapid trains the gap is 1 cm and the calculation frequency is 15,000 times per second [13].

As the practice and experience of adapting the Eurocode during compiling special technical requirements for the Moscow-Kazan high-speed railway [14] shows that the traditional model of load “SK” from [15] is not suitable for calculating bridge structures for high-speed trains, because it is unable to simulate the dynamic impact that real train does.

For calculations of bridge structures under magnetic levitation transport we use a load which is technique equivalent to HSLM from Eurocode[9] – the train is modelled by a set of concentrated forces that move along the span structures with a certain speed. But unlike the case of calculation of trains based on the "wheel-rail" technology, in maglev train case, the concentrated force is modelling not the wheel pair, but the pole of electromagnet.

In this investigation the calculation was accept model based on Transrapid maglev train. The central carriage of this train is on Figure 3.
Figure 3. Calculation model: 1 - car body; 2 - damper; 3 - frame; 4 - section of bottom magnets; 5 - section of side magnets.

Transrapid train consists of 3 carriages, each has 4 frames on both sides, 12 sections are mounted on the frames, the distance between magnet poles is 0.258 m. The weight of one car is 39000 kg, the weight of the frame is 660 kg, the section magnets - 603 kg. [16-18].

3. Results of experimental studies, practical significance

The calculations were performed in the Midas Civil software. In this research the analysis of the optimal design maglev train model was promoted, the values of vertical deflections and accelerations were calculated on the speed range from 0 to 1000 km. This range exceeds the operational range for the Transrapid train (0 ... 500) due to the promising developments of the maglev trains located in the vacuum tube [3].

Based on the received loads, the total weight of the train was 160,578 kg. It is evenly distributed on 23 sections of magnets (each at 3.096 m), 6982 kg on one section.

Two loading schemes were used to specify the load. Scheme 1 provides the distribution of the weight to the section by 3 concentrated forces (2337.4 kg, respectively, for one concentrated force) – Figure 4a. Scheme 2 replaces each of the 12 magnets with a concentrated force (584.35 kg per one concentrated force). Scheme 2 requires a much more detailed model of a span structure – the distance between nodes is 0.1 m, while in the Scheme 1 – 0.5 m.

As a basis for a beam span structure, a 24 m long, reinforced concrete beam is used in China. Cross section - figure 5. Material - reinforced concrete with a modulus of elasticity of 4.05 * 10^7 kN/m², the damping coefficient is 0.0025. The deflection at a static application of a given load is 1.718 mm, the first horizontal frequency is 7.96 Hz.
The calculation data are given in table 1

| V, km/h | Scheme 2 | Scheme 2 |
|---------|----------|----------|
|         | A, m/s²  | DZ, mm   | A, m/s²  | DZ, mm   |
| 100     | 0.154    | 1.739    | 0.2244   | 1.738    |
| 200     | 0.2826   | 1.74     | 0.6986   | 1.74     |
| 300     | 0.3958   | 1.77     | 0.89     | 1.77     |
| 400     | 0.5241   | 1.829    | 0.9914   | 1.828    |
| 500     | 0.8726   | 1.809    | 2.1      | 1.808    |
| 600     | 1.545    | 2.049    | 1.655    | 2.047    |
| 700     | 1.782    | 2.27     | 2.286    | 2.269    |
| 800     | 3.035    | 2.455    | 3.302    | 2.452    |
| 900     | 3.177    | 2.603    | 3.387    | 2.599    |
| 1000    | 3.543    | 2.719    | 3.526    | 2.716    |
| 1100    | 3.511    | 2.813    |          |          |
| 1200    | 4.014    | 2.888    |          |          |

Results shows that the magnitude of displacements does not depend on the scheme, while the difference in value of accelerations during the transition from scheme 1 to scheme 2 is very significant. Therefore, in the framework of studies which not require computation of accelerations – for example, determining the value of the dynamic coefficient, scheme 1 is more preferable. While issues related to the calculation of the values of accelerations require further optimization of scheme 2 in order to obtain data adequate for field research.

But proceeding from the data obtained, a significant global conclusion can be drawn, which shows a significant difference in the nature of the transfer of load between maglev trains and conventional railways. This conclusion is the lower value of the dynamic coefficient of the train maglev - figure 6.
As we see on the operational range of trains Transrapid 0-500 km / h - this value of dynamic ratio does not exceed 1.07. While conventional trains based on ‘wheel-rail’ technology have this parameter in the range of 3-4[19-20]. This phenomenon is explained by the small distance between concentrated forces in the model of maglev train. For example the train A1-A10 has distance which determining the frequency of the action is 18 - 25 m [9], but in the scheme 1 the given distance is 1,032 m, and in the scheme 2 - 0,258 m. Due to this the maglev trains have a significantly higher frequency than the span structures, thus maglev not causing a resonance on high speeds. Nevertheless, for the same reason, the lower speed range should be studied in more detail during further research into possible resonances, which, as practice shows, take place on the route to Pudong Airport [21-22].

4. Conclusion
The proposed calculation model opens up broad prospects for further research:
- Determination of the optimal span length;
- Optimization of the beam proposed in China (since the resulting deflections are 1/13969 with a tolerance of 1/4000);
- Searching resonance peaks at low speeds;
- Studies damping elements in the scheme.

The method of calculation presented here gives an idea of the dynamic response of the infrastructure during the magnetic levitational train passes through it. The data obtained from it, the calculated models used can be used in further studies of optimizing beam span structures for a specific Russian prototype of a magnetic levitation train and creating special technical conditions for maglev transport.

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