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CHANGE IN THE COIL DISTRIBUTION OF ELECTRODYNAMIC SUSPENSION SYSTEM

Hisashi Tanaka
Japan Railways, Railway Technical Research Institute

SUMMARY

At the Miyazaki Maglev Test Center, where test runs started with superconducting coils paralleled with ground levitation coils, that is, the facing levitation system, (after the development of the superconducting coil with a high magnetomotive force which makes it possible to levitate, propel and guide a maglev train only by this superconducting coil), the coil distribution has been changed to the facing levitation system where both types of coils are located perpendicular to each other, and then further changed to the side wall levitation system with practical tests near at hand on the new Yamanashi Maglev Test Line. Here, our approach to the project is introduced.

INTRODUCTION

In the days of the now defunct Japanese National Railways (JNR), a maglev transportation system featuring superconducting magnets, electrodynamic suspension, active track linear synchronous motor propulsion and null-flux magnetic guidance has been selected as a system desirable for future high-speed ground transportation. The reasons are as follows:

(1) It is possible to run at a high-speed of 500 km/h or more.
(2) This system is advantageous in the aspect of noise because the vehicle runs completely non-contacted with track surface, and saves the track and vehicle maintenance troubles.
(3) The comparatively large air gap of about 100 mm between a vehicle and the track surface ensures the safety even with earthquakes.
(4) The levitation system adopting a self-stabilizing system needs no special control.

The electrodynamic suspension is divided roughly into a system with sheet on the ground and one with coils on the ground. The coil system is adopted because

(1) Magnetic drag is less.
(2) The degree of freedom in design is higher.

The related work started in 1970. Since 1977 test runs have been carried out on the Miyazaki Maglev Test Track. Recently the basic technology development stage has been virtually completed, and a decision was made to proceed to practical tests on the Yamanashi Maglev Test Line which is now under construction. In step with the development of superconducting coil and with progress on related tests, the coil distribution has been modified twice. The back ground concept is to be described.

FACING LEVITATION SYSTEM WITH PARALLEL COILS

At the time when the Miyazaki Maglev Test Track was planned, the magnetomotive force of a superconducting coil able to be manufactured was about 450 kA, so the superconducting coils were located separately for levitation and for propulsion (Fig. 1a, Fig. 2a). The coil surface of a levitation superconducting coil (250 kA) was faced horizontally a levitation ground coil which was also horizontally, thus constituting a facing levitation system. The coil surface of a propulsion superconducting coil (450 kA) was faced vertically. A propulsion ground coil was also vertical, thus constituting a linear synchronous motor. For guidance, instead of setting coils for this, the propulsion coils located on both sides of the track facing each other were connected to form a loop resulting in a null-flux circuit.

At the beginning, assuming that cycloconverters serve as the power converters, the technology, then had output frequency limited to about one third of the input frequency. Supposing that the input is a commercial frequency (50 Hz or 60 Hz in Japan), the pole pitch will be more than 3.5 m. The Miyazaki Maglev Test Track was intended for first stage test runs. In order to minimize the necessary track length, acceleration was set larger (0.3-0.4 g), which shortened the track length to 7 km. The length of a test vehicle was set at 10 m, which makes the length of the superconducting coil portion of the vehicle equal to 8 m. For a larger thrust, 4 poles are needed with a pole pitch of about 2 m, so the commercial frequency (60 Hz in Miyazaki Prefecture) was stepped up to 120 Hz through a motor generator. The pole pitch of 2.1 m, a multiple of 3, was taken finally because a three-phase alternating current was to be used. Consequently, the pitch for the propulsion ground coil is 1.4 m. As for the levitation ground coils, the pitch is 0.7 m, which is calculated from the pitch ratio 1:3 for levitation coil vs. superconducting coil in order to suppress the fluctuation of levitation force.

In order to concentrate thrust and brake force around to the gravity center of a vehicle because of a larger acceleration as mentioned above, an inverted-T shaped cross section was adopted for the guideway. The ground coil for both levitation and propulsion is made of rectangular aluminium wire coil and sheet mold compound. The superconducting coil is of the race track type so as to avoid the magnetic field concentration. Because the maximum empirical magnetic field about 5 T for the magnetic levitation is not so high, the wire made of niobium titanium alloy series has so far been consistently used. However,at that time the stability depended upon copper with a higher copper ratio of 5 to 6. The coil of both types for levitation and propulsion are housed in a cryostat of L-shaped cross section.

In December 1979, an ML-500 test vehicle on the inverted-T shaped guideway registered a maximum speed record of 517 km/h, surpassing the target speed, which demonstrates the high-speed running ability of this system.

For the inverted-T shape guideway, the framework mounting the superconducting magnets is designed in an arch type. In addition the opening and shutting vibrations due to repulsive forces occurred, causing the framework to be broken, which plagued us. ML-500 is an unmanned test vehicle. Taking into account the commercial version, the vehicle body is mounted on the arch shaped framework, so the vehicle becomes inevitably taller.

FACING LEVITATION SYSTEM WITH PERPENDICULAR COILS

Later, the guideway was re-modelled to a more practical U-shaped cross section. In the meantime, as it has become possible to manufacture a superconducting coil with a magnetomotive force of 700 kA class, one superconducting coil can perform all the functions of suspension, guidance and propulsion (Fig. 1b, Fig. 2b). Thus the vehicle construction has been substantially simplified. Out of necessity for propulsion and guidance, the coil surface of superconducting coil is made vertically. Thus a facing levitation system has been adopted as a levitation mechanism in which a superconducting magnet is located at right angles to a levitation ground coil. As for the ground coils, the levitation coil remains unchanged, while the propulsion one has been transferred to the side walls.

When an intrinsically stable wire using ultra-fine core has been manufactured as a superconducting wire, light weight by decreasing the copper ratio is realized and the direct contact with liquid helium is needless, making it possible to strengthen the wire through epoxy impregnation. An inner vessel has been transformed into a tube, resulting in an increased strength. In addition, a much decreased cross section of the vessel reduces the charge of liquid helium.

The superconducting coils are arranged continuously in the running direction and the passenger room comes just above the superconducting coils; accordingly, a 2.3 mm thick steel plate is laid on the floor as a magnetic shielding. As a result, the strength of the magnetic field in the room is about 20 mT on the floor surface, 10 mT on the seat, 5 mT on the passenger's back, and 3 mT at the head rest portion of a seat.

Three U-shaped MLU001 test vehicles have been manufactured. In February 1987, a 2-car unit manned by three persons registered a maximum speed of 400 km/h.

In order to investigate vehicle dynamics related to guideway irregularity, test runs have been carried out with various artificial irregularities created on the viaduct beams and in the coil distribution (Fig. 3, Fig. 4). The test vehicles have passed safely over the irregular sections with an enough air gap sustained in all test runs, which confirms the advantage of the electrodynamic suspension system with a large air gap. Further, the vehicle vibration due to the irregularity has been damped within one wave, verifying the sufficient damping ability of the system.

SIDE WALL LEVITATION SYSTEM

In parallel with test runs of the Miyazaki Maglev Test Track, the structure of a commercial maglev vehicle also has been elaborately examined (Fig. 5). At first, the maximum magnetomotive force of a superconducting coil available at that time was about 500 kA, so it has been planned to arrange the coils continuously in the direction the train is running. Thereafter, as the magnetomotive force is raised, a system in which a decreased number of coils are concentrated over the coupling position of an articulated train has been mainly examined. The decrease in superconducting magnets contributes to lighter vehicles, decreased costs, improved ride comfort derived from a larger mass ratio of vehicle body vs. bogie, and easier magnetic shielding of the passenger space. Moreover, the research on a circulating current type cycloconverter through which the output frequency is upped to about two thirds of the input frequency has been advanced, which makes it possible to decrease the pole pitch.

The MLU002 test vehicle has been built with the main target of testing the system with concentratedly distributed superconducting coils (Fig. 1c). The rated magnetomotive force has been raised from 650 kA for MLU001 to 700 kA. However, since the decrease in the number of superconducting coils lowers the electromagnetically levitated height, the copper ratio of superconducting wire has been reduced to 1 instead of 2 for MLU001 and the current density has been increased from 173 A/mm^2 to 219 A/mm^2, resulting in a reduced cross section of superconducting coil. At the same time, the cryostat's cross section has been reduced. All these efforts have contributed to maintaining the air gap of 100 mm. Consequently, however, the superconducting coils have been weakened, inducing sometimes a quenching during test runs. As a countermeasure against this, the current density has been lowered to about 180 A/mm^2 or less to yield a margin. In addition, the cross section of a coil and an inner vessel have been widened to increase the rigidity.

The articulated vehicle has fewer superconducting coils than the MLU002 test vehicle does, which increased the load (Fig. 1d). Moreover, to protect pacemakers inplanted in a passenger's body the magnetic field of the passenger space must be minimized to about 1 T. The decrease of pole pitch is being examined to strengthen the superconducting coil and to lower the magnetic field. When these things materialize, the straight portion of a superconducting coil will be decreased, which means a shortage of levitation force for the facing levitation system, so it has been decided to change the levitation system from facing levitation to side wall levitation. In the meantime, with a recent advance in the GTO thyrister, the power converter will be switched to an inverter, so there will be no problem when the frequency is increased due to the shortened pole pitch.

For the side wall levitation system, the levitation ground coils ("8"-figure coils) formed by invertedly connecting two loop coils are set on the side walls. The repulsive and attractive forces acting between the horizontal coil edges of both superconducting coils and "8"-figure coils yield a levitation force larger than the facing levitation system does in spite of the same current rate for both systems. With the generated levitation force being the same for both systems,the smaller induced current is sufficient for the side wall levitation system, resulting in a smaller magnetic drag. Furthermore, when the wheels run with the superconducting magnet center falling upon the "8"-figure coil center, the induced current is not generated in the "8"-figure coil and the magnetic drag due to the coil loop is null. The side wall levitation system is one in which the balance point is clear. For this system the magnetic spring coefficient in vertical direction is more rigid, so the superconducting magnets must be installed on the bogie with the elasticity being maintained.

For the side wall levitation system, using the levitation ground coil as a null-flux circuit for guidance can be constituted. Thus, it is possible to eliminate the high voltage for propulsion from the null-flux cable.

Moreover, because it is found that a greater fluctuation of the magnetic field under the conventional single layer distribution of propulsion coils generates more heat within the superconducting magnet, the coil distribution will be converted to a double layer one as a countermeasure. The commercial system will be located with a high voltage of about 22 kV to haul a larger train. Epoxy resin etc. will be used for the formation of propulsion coils.

These coil distributions have already been tested on the part of the Miyazaki Maglev Test Track (Fig. 2c, Table 1, Fig.6, Fig. 7). While the construction of the Yamanashi Maglev Test Line is in progress, more elaborate recognition tests will be undertaken on a prolonged modified section of the Miyazaki Maglev Test Track.

The side wall to be installed with all ground coils must be erected with high accuracy to secure a good ride quality of the vehicle. The other requirements of the side wall are as follows: easy elimination of the irregularities due to aging; smaller deformation under condition of vehicle running and meteorological conditions such as insolation; less steel consumption such as reinforcing steel rods in order to lower the magnetic drag. To meet these requirements,a guideway of beam structure is under development.

As for the non-contact current collection on account of the on-board items such as lighting, air-conditioning, and refrigerator drive, the efficiency will be down in comparison with the facing levitation system which is more efficient in this respect. Special care should be taken such as providing a superconducting coil specialized for power collection.

Because the gangway runs over the upper part of superconducting magnet, the part must be shielded magnetically. The application of high-temperature superconductors to this part is being studied.

CONCLUDING REMARKS

In Japan, at first the electrodynamic suspension system was developed exclusively for passenger transportation because passenger traffic is predominant in this country. The land being mountainous, it is impossible to do without tunnels, so it is imperative to decrease the cross section of a vehicle as much as possible. In addition, taking into account conditions such as lighter vehicle, lower costs, improved mass ratio of vehicle body vs. bogie, and easy magnetic shielding, the superconducting coils in a commercial system will have to be located just over the junction between vehicles. In addition, the levitation system has been changed to a side wall levitation system, in which an ample suspension force will be secured even when the pole pitch is decreased to strengthen the superconducting coils and to lower the magnetic field on board. The two layer coils complicate the ground structure a little, raising a future problem of lowering the construction costs. A different alternative will be taken when there is no tunnel, for vacuum tube transportation, or for freight transportation, etc.

Lastly, it should be added that this development project has been subsidized by the Japanese Government.

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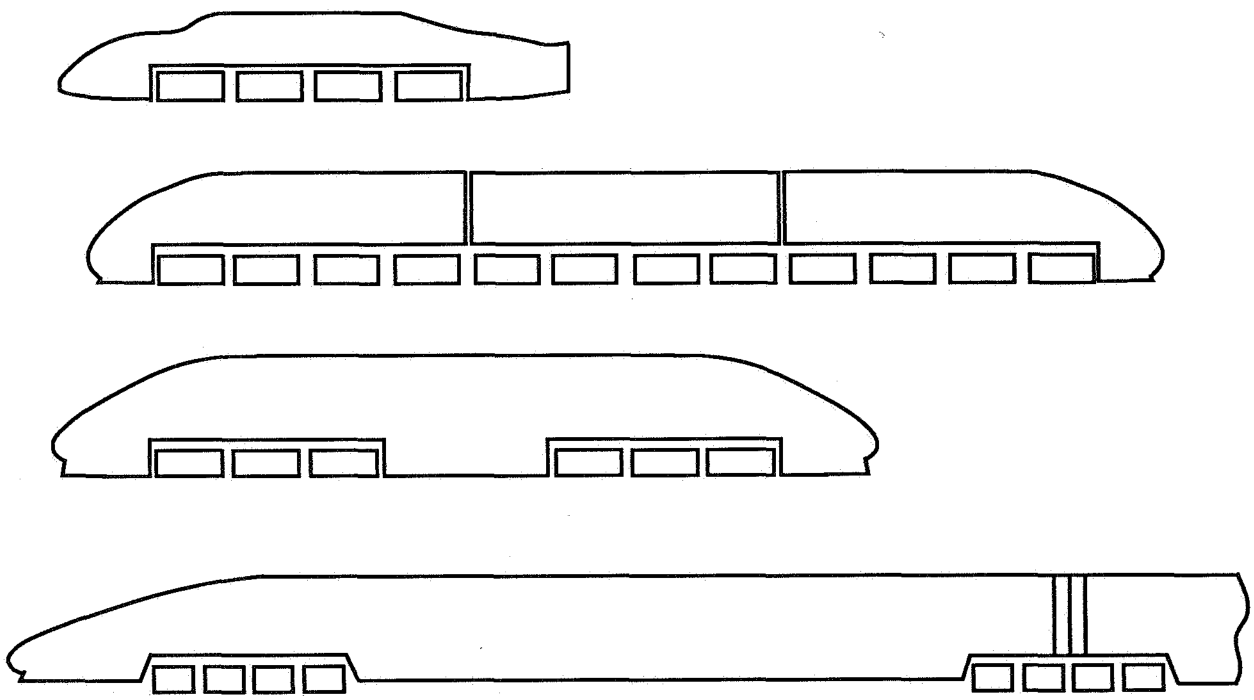
Table1 Coil Parameters of Miyazaki Side Wall Levitation

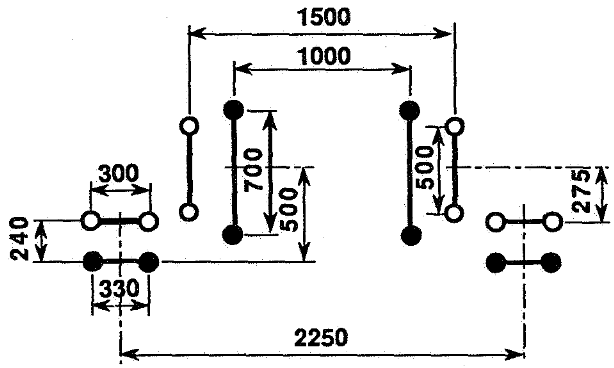
Superconducting coil	Length×Width Pole pitch Magnetomotive force	m m kA	1.7×0.5 2.1 700
Ground coil (per one loop)	Length×Width Number of turns Resistance Inductance Height of loop center	m mΩ mH m	0.55×0.31 36 24 0.89 0.195
Between coil centers(Gap)		m	0.2

(a)
(b)
(c)
(d)

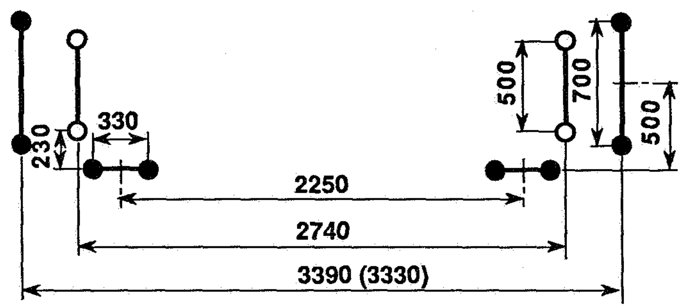


(a) ML-500 (b) MLU001 (c) MLU002 (d) Commercial Version

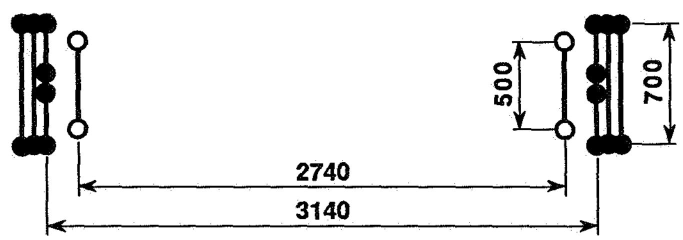
Fig.1 Coil Distribution of Test Vehicles



(a) Facing Levitation System, ML500



(b) Facing Levitation System, MLU001, ( ):MLU002



(c) Side Wall Levitation System, MLU002

O—O On-board superconducting coil ●—● Ground coil

Fig.2 Coil Distribution of Miyazaki Test Track

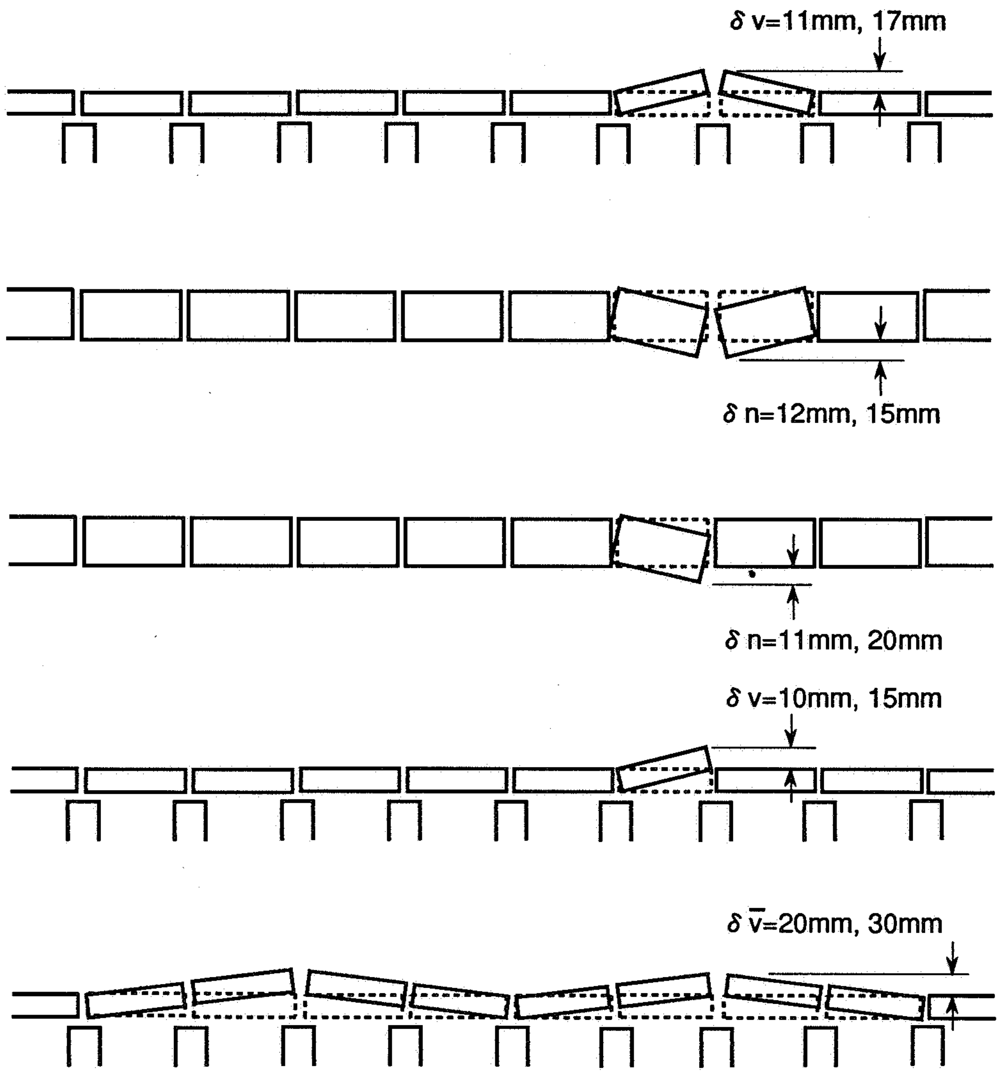
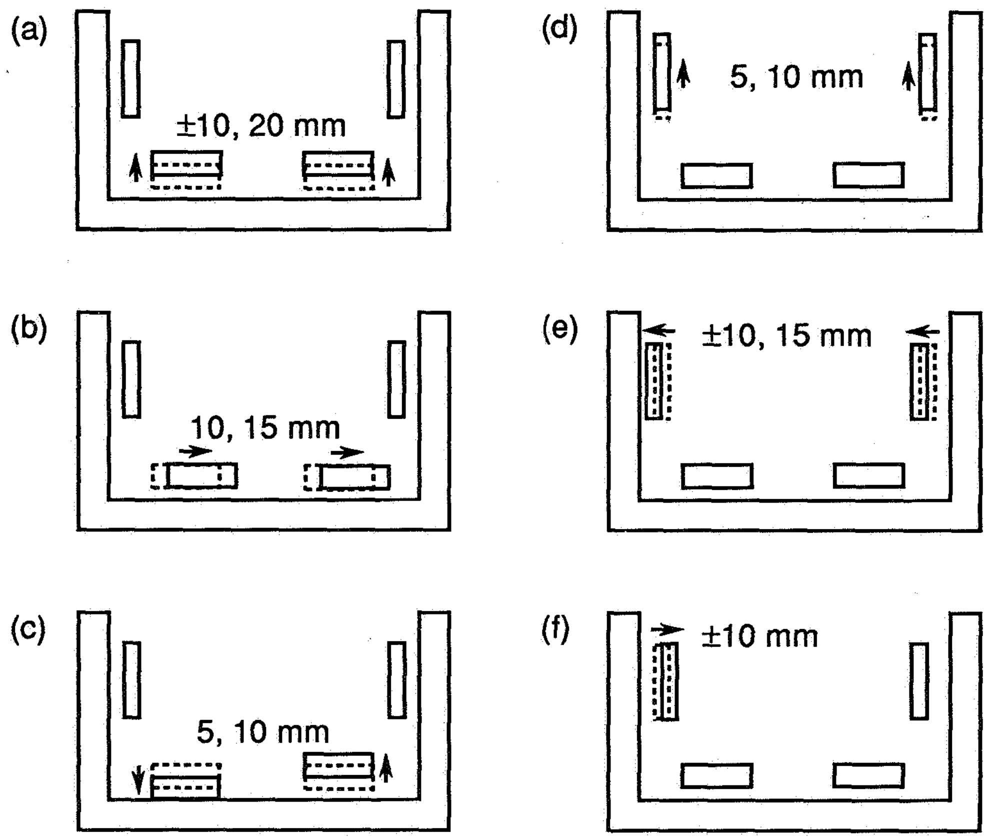


Fig. 3 Guideway Irregularity Test



L = 46.2 m ----- (b), (c)
50.4 m ----- (a), (d), (e)
168.0 m ----- (f)

Fig. 4 Coil Irregularity Test

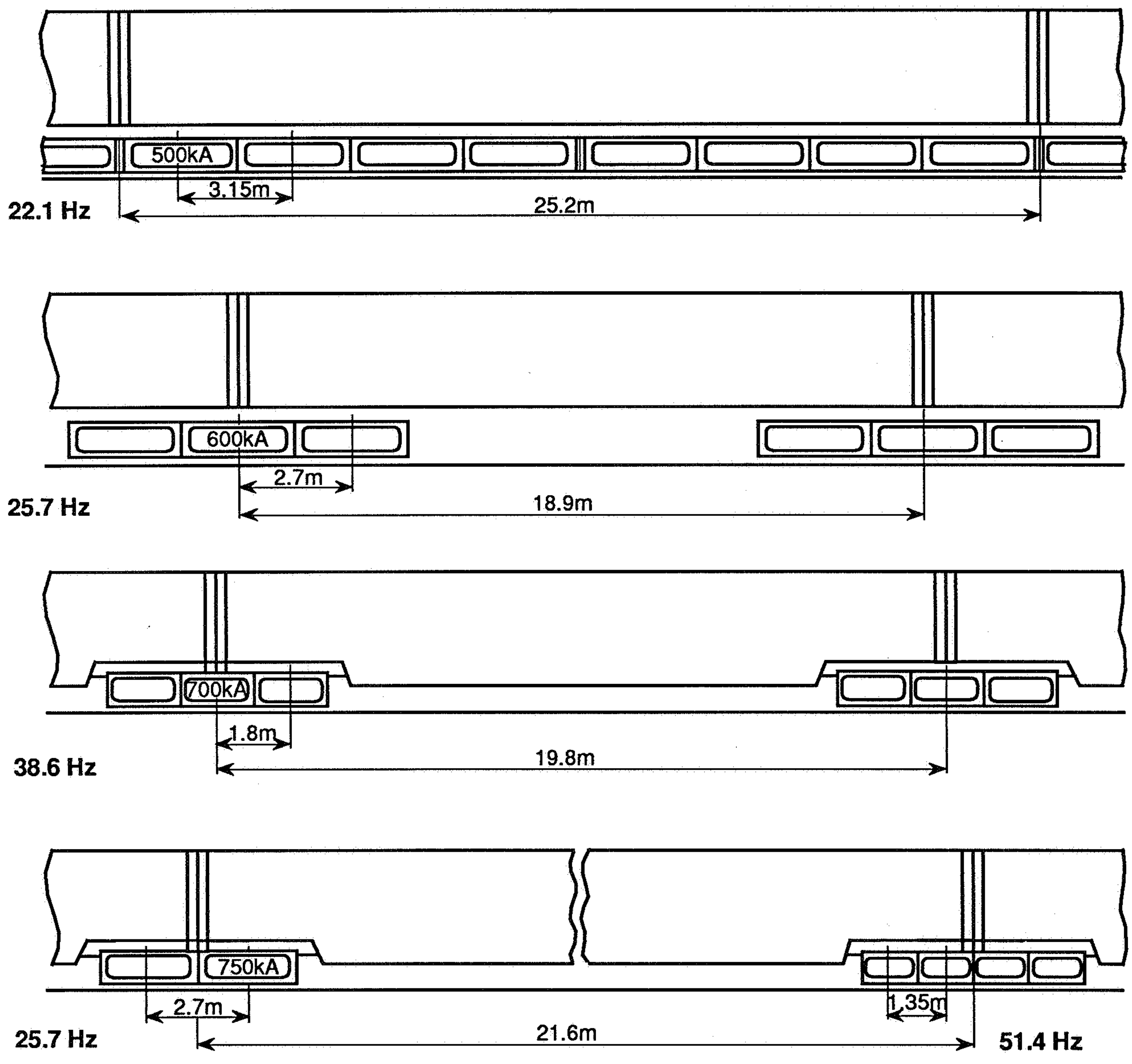


Fig.5 Progress of Investigation on Commercial System

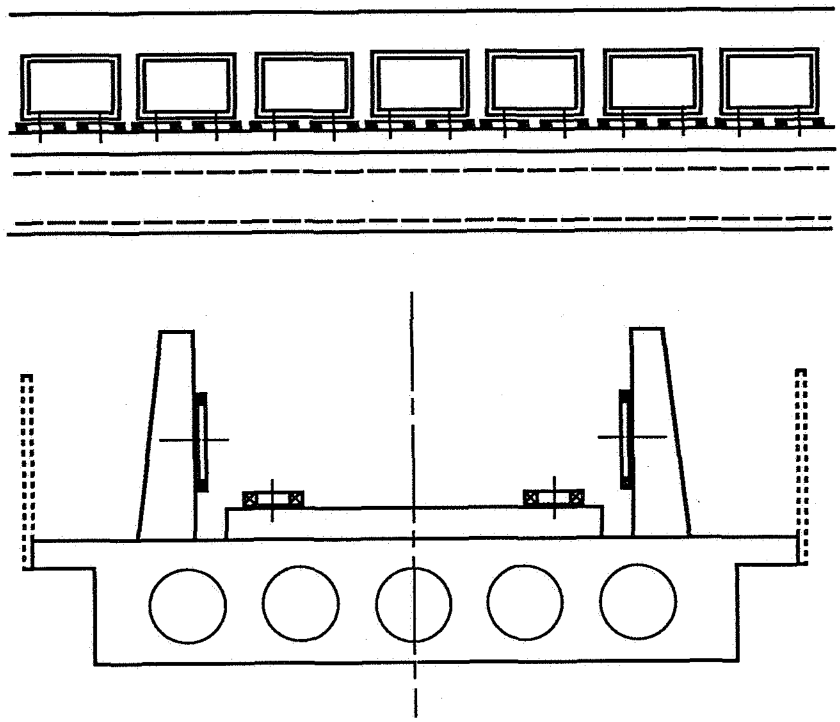


Fig.6 Miyazaki Guideway in Facing Levitation System

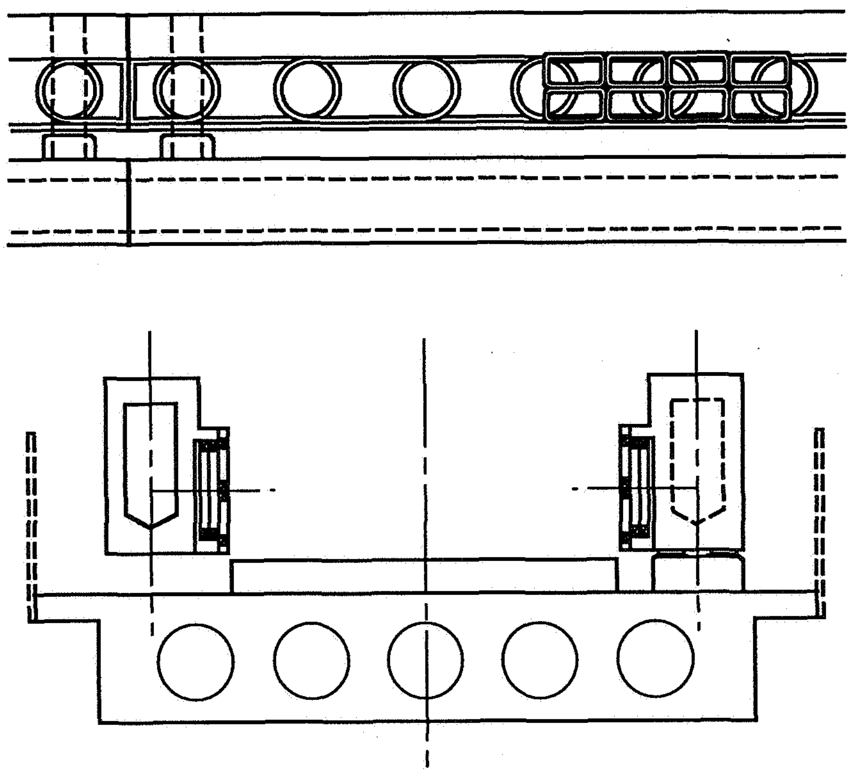


Fig.7 Miyazaki Guideway Converted to Side Wall Levitation System