Failure Mode and Endurance Tests of the HSST 100L System

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Synopsis

Since the HSST-100 system was validated in 1991-2, and subsequently endorsed by the Japanese Ministry of Transport in 1993, continual development and enhancements have been made to the HSST-100 system. Recently, with a collaborated effort between CHSST and KCRC, a series of failure mode and endurance tests have been conducted to investigate the robustness and endurance performance of the HSST-100L vehicles. The objective of these tests was to study the HSST-100L system behaviour and establish data to examine whether it is feasible to be adopted for implementation in a high throughput and high passenger volume type mass transit application.

A thorough scenario and failure analysis was conducted in order to identify appropriate test cases. The test cases identified were in the main of a non-destructive type to avoid any damage to the vehicle. A number of system performance tests were carried out, e.g. levitation magnet failure, track-side noise and in-saloon magnetic field strength tests. The paper will focus on the critical factors, failure mode and abnormal mode tests which give some insight into the possibility of adopting the 100L system for a mass transit environment. The paper will also detail the results and observation of the endurance test which involved 5 consecutive days of 19-hour continuous operation of the 100L vehicles at the Nagoya test facility.

1. Introduction

1.1 Background

In August 2000, the Kowloon Canton Railway Corporation (KCRC) commenced a study into the technical and operational aspects of introducing Maglev as an alternative form of rail transportation.

The objective of the study was to evaluate the merits/demerits of introducing such a form of rail transport into the Hong Kong environment, as either a future replacement for existing rail infrastructure and/or in conjunction with the rail development programme envisaged by the Hong Kong Government in the coming 10-15 years.

Much had been written about Maglev systems, but the KCRC senior management determined that it was essential that KCRC engineers undertook there own independent study of the systems available on the world market, and how such systems could be incorporated into the KCRC network, developing an overall business case, as a comparison against conventional wheel on rail technology.

Visits to all the manufacturers of Maglev systems were undertaken, to gauge the status of current developments and to gain an overall appreciation for the products. It was evident from these initial visits that there was no product in the market place that met our operating criteria. KCRC vision saw Maglev very much as a potential alternative to its current EMU operation, with trains conveying upto 70,000 pphpd at speeds below 150 km/h.

The technical study involved many months of detailed discussions with the engineers responsible for the design and development of the vehicles, the guideway and the vehicle on board systems. Whilst the discussions focused on the technical and operational aspects of placing the product into service, it was recognized that for completeness, a series of trials should be undertaken to verify a series of "what if" statements. KCRC generated in conjunction with the suppliers a list of "what if" statements for translation into operational trials.

The trials were conducted over many weeks. In addition to specific tests, a continuous operation trial was included to simulate operating time cycles of nineteen (19) hours a day, as would be essential for operation in Hong Kong.

The paper provides an insight as to the types of "what if " statements that were performed during the trial period, and the findings, as applicable to the CHSST vehicle.

1.2 The Test Trial Set-up

The test trials were conducted in December 2000, with 2 HSST 100L vehicles coupled back to back at the CHSST test facilities in Nagoya, Japan. The two vehicles were equipped with different traction drive packages. The MC1 vehicle (trailing outward trip) being equipped with IGBT traction drives was fully loaded at 25 T, while the MC2 vehicle (leading outward trip) equipped with GTO traction drives was not loaded with a tare weight of 17 T. The vehicles were set to manual driven mode with the on-board ATO cut-off to facilitate the simulation of failure mode scenarios. This configuration was used throughout the trial period.

2. Vehicle start/stop sequence

Four tests were carried out, one at the level and straight section, one at the middle of the 7% up grade, one at the middle of the 7% down grade, and one at the 100m curve section respectively. Test data and traces including vehicle speed, levitation gap, magnet current, brake signal, linear induction motor (LIM) input current and brake notch versus time were obtained from the on-board data logger. For each respective test, the train was brought to the planned starting location, de-levitated and re-started to observe the operating sequence. The start/stop commands were initiated from the control console in the driving cab which is equipped with a LCD train management system display showing the levitation conditions of the train, speedometer, traction/brake command handle, and push buttons for various functions such as train levitation/de-levitation, emergency stop and train-start-from-up-gradient. The start/stop sequence of the 100L for the 7% down gradient, level and curved track scenarios were very much similar to the start/stop sequence of a conventional manually driven train. Powering, coasting and braking commands were achieved through the traction/brake handle. The train was stopped by the application of hydraulic service brake. When the train was stopped and de-levitated, the train was held at the position by means of skids. When the 100L was started from the 7% up gradient from de-levitated condition, the train-start-from-up-gradient button was first used to hold the train before the train was levitated. The on-board control system released the holding brake 3 seconds after the LIM was energized. This re-start process being slightly different from the conventional train avoids the train rolling-back.

3. Service and emergency brake at maximum down gradient (7%)

Tests were conducted for service and emergency brake at 70 km/h and 80 km/h respectively. Test data and traces were obtained from the on-board data logger as described previously. The train was stopped effectively and there was no rattling or any brake deficiency found. Inspections of the iron rail and brake pads were carried out afterwards. There was no visible wear and tear due to the tests, apart from the rust on the iron rail being rubbed off by the brake pads. There was some gap fluctuation shown on the traces, but they were all well within the 4 mm gap tolerance. The performance of the service and emergency brake being smooth and quiet were considered better than heavy mass transit rolling stock.

4. Gap sensor failure

Tests were conducted with the train stationary in the depot and running at the level section at 30 km/h. Gap sensor failure (module 7) was simulated by switching off the power supply to the sensor circuit by means of a temporary manual switch. The module was landed on skids when the power supply to the sensors was cut off. For the train running at 30 km/h case, the module was first landed on skids, the services brake was applied in about 2 second after the module landing. The train was stopped accordingly. It can be seen from the trace that the magnet current (module 7) was increased momentarily in order to maintain the gap tolerance, when the gap sensor failed. There was very little disturbance in terms of gap fluctuation at the adjacent modules.

5. Magnet module failure

Four tests were conducted with the train stationary in the depot and running at the level section at 30 km/h. The test results and landing sequence were similar to gap sensor failure scenario. Test data and traces were produced. With a whole module failure, the disturbance to adjacent modules was slightly higher than the gap sensor failure case.

6. LIM failure (one side fails)

Two tests were conducted with the LIM's on one side of the MC1 vehicle disconnected. The first test was conducted with the train started up from the bottom of the 7% gradient. 50 km/h was achieved at the top of the 7% gradient. The second test was done with the vehicle running from Tomeiko to Oye (refer to the test track shown in the appendix). 70k m/h was achieved. Traces of the LIM modulated input current were obtained which showed the LIM current at motoring, coasting and electrical braking modes. There was no instability nor excessive vibration found due to the imbalanced propulsion on the MC1 vehicle. It is noted that the installed power on board was sufficient in push/pull mode operation at 50 % degradation.

7. Vehicle running on rollers

One round trip of the complete test track was carried out with the MC1 vehicle on rollers and the MC2 vehicle levitated. The jack-up rollers were switched on through a manual switch in the cab. It took about one second to complete the whole "jack-up" operation. The train was run up to 30 km/h. The in saloon noise level was increased significantly. This was considered attributable to the wheel bearing and roller guideway contact, in particular when the rollers were passing over the guideway gaps. Albeit the increased noise, the ride was found to be smooth and stable. Inspections of the guideway were carried out afterwards, there was no obvious scratching on the guideway. Noise emission measurements were carried out. All test data were measured at 10 m from the guideway centre with the train moving at different speeds at the straight section. The background noise was around 60 db(A), this increased to 65 db(A) when there were lorry/trucks passing-by on the adjacent road. When the train was levitated and running at 80 km/h, the pass-by noise level was about 68 db(A). When the train was running on rollers at 30 km/h, the pass-by noise level was about 96 db(A). It is recognised that improvements could be made to the bearing and the rollers, e.g. resilient rollers, to reduce the noise level under emergency operation.

8. Emergency landing

Four tests were conducted with one in the depot, one on straight section, one on 7% up grade and one on 7% down grade respectively. For the straight section test, the train was brought to stop from 20 km/h purely by the skids. For the 7% gradient tests, the train was brought to stop from 30 km/h purely by the skids. During the landing process, there was no excessive noise nor vibration. Inspections of the guideway were conducted afterwards, there were visible marks made on the guideway rail, but these being of no consequence.

9. Objects on guideway

Tests were conducted with different kinds of objects placed on the guideway to test the effectiveness of the deflector plate, with the vehicle moving at slow speed in the depot area to simulate train movement at a station, as well as at the straight section at 30 km/h. Aluminium cans, pebbles, aluminium foil, newspaper, glove and coin were placed on the guideway. All objects were swept away, apart from the newspaper and aluminium foil which were trapped underneath the cow-catcher. Discussions were made afterwards, it was envisaged that improvements could be made by adding a heavy duty plastic brush to the front end of the deflection plate to minimize the gap distance between the cow-catcher and the guideway surface. An under vehicle inspection was carried out, and no visual indication of any damage of any kind was found.

10. Gap sensing fluctuation

Test data and traces were obtained during the test period. It can be seen from the traces that the magnet current varied in accordance with the air gap fluctuations. The initial start-up (levitation) period and the soft-levitation process was clearly shown on the traces, which took about 2 seconds.

11. LIM and levitation magnet temperature

A twelve hours temperature rise test was conducted to observe the temperature rise characteristics of the LIM's and magnets at the leading and trailing bogies. Traces and data were obtained from the on board temperature data logger. The LIM's and magnets are insulated with Class F material. It can been from the traces that there was very little difference in temperature compared between the LIM's of the leading and the trailing bogies. Regarding the magnet temperature rise, it was found that the magnet of the trailing bogie was almost constantly about 15 degree C higher than the magnet of the leading bogie. This may be due to the better air circulation in the front. It can also be seen from the traces that there were some sharp spikes which were due to interferences from the LIM's which affected the performance of the measuring equipment. But, it was not difficult to establish the overall trend and saturation of the LIM's and magnet's thermal characteristics. In summary, there is plenty of margin for the LIM's and magnets to operate in a higher ambient environment, as the result shows that the temperature of the LIM's and magnets under test became saturated at about 58 degree C and 65 degree C, at 22 degree C ambient temperature.

12. Residual flux in the iron rail and magnetic field strength in saloon and along trackside

Magnetic field strength was measured in saloon and along track side with the vehicle stationary and moving at 40 km/h. There was obvious remnant flux in the iron rail. The highest measurement was 0.77mT at the iron pole face which was about 23% lower than the European Norm (EN 50061, EN 50121) requirements. It was found that residual flux in the iron rail was only increased by about 0.1mT after the magnets were energized for 10 minutes. All the magnetic field strengths measured were well within International Standards specific for railway applications.

13. Uneven loading of the MC1 vehicle

A test was conducted with the loads on the MC1 moved to one side to simulate a 40/60 (20-25%) uneven loading scenario. A round trip was carried out with the vehicle running at 70km/h. The ride was smooth and with no instability. As 25% overloading was design based on 10 standee per square metre, in reality, it would not be possible for the existing 100L to accommodate more than 10 standee per square metre, and this requirement was used for the design of the car-body strength.

14. Endurance test

A 5-day 19 hours endurance test was conducted with the train travelling at 70-80 km/h simulating a normal train service in an urban transit environment. A round trip took about 6 minutes including dwell times, change end operating time etc. A minor incidence occurred during the whole endurance test period which was related to a sluggish pressure valve resulting in some downtime. It is envisaged that enhancement could be made to increase reliability.

15. Concluding Remarks

The trial was satisfactorily conducted with the competent assistance from CHSST. A better understanding of the dynamic behaviour of the CHSST 100L system was made possible through observation and detailed discussions with CHSST engineers. In some areas, particularly EMC, the performance of the system conformed well within International Standards. The magnetic field strength of the 100L was about an order lower than that of a conventional EMU train.

In summary, the 100L system performed very well in terms of ride quality, accelerating and braking characteristics, noise and vibration level. Based on the 5-day 19-hour continued endurance test, it is obvious that some minor improvement will need to be made in terms system reliability and availability. Nonetheless, these could be engineered into the system through prudent system design in conjunction with careful operation and maintenance planning.

The 100L system in its current state is adequate in all aspects in providing a train service of light capacity, apart from the availability and reliability department which as above-mentioned would need to be enhanced in terms of fault tolerance and redundancy. Since the vehicles were built, the advances in power electronics and computer technology have been made in an ever increasing pace. With these benefits, the future version of 100L could very little doubt be made more reliable for revenue service. For a higher passenger capacity though, there are some design changes to be made, such as the width of the vehicle, lift capacity, seating arrangement, and additional on-board automation required for driverless operation. The risks associated with these changes would need to be managed carefully and sufficient lead time should be allowed for prototyping, testing and validation.

16. Acknowledgement

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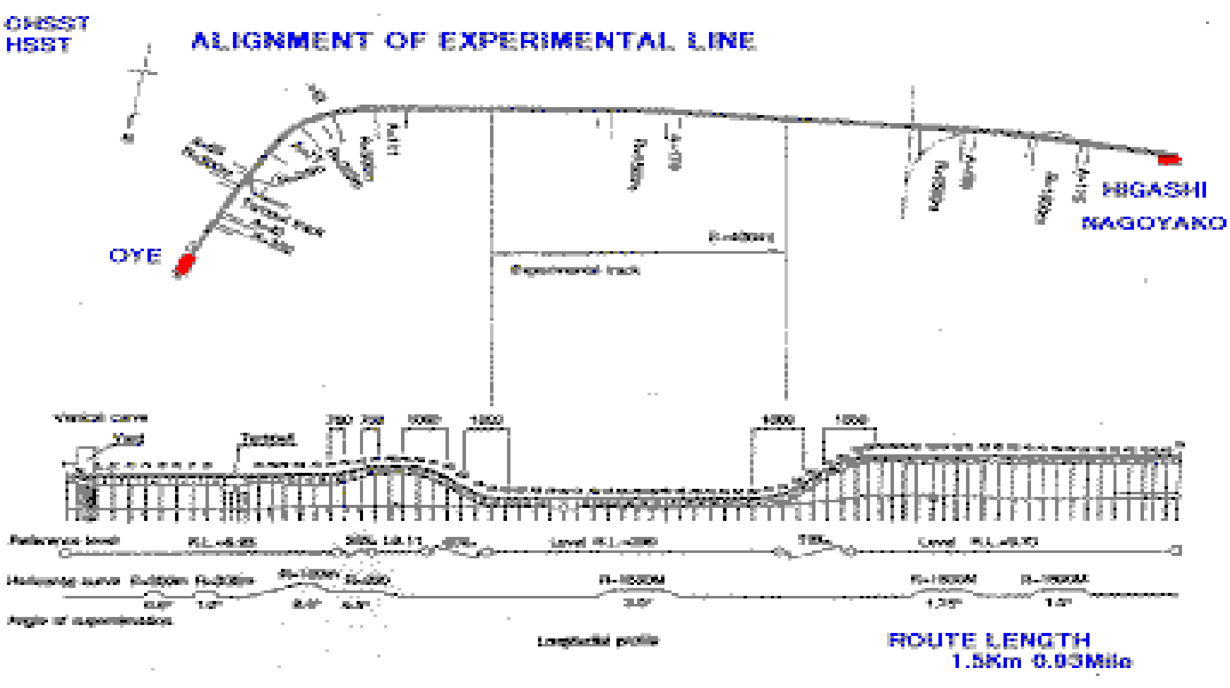
17. Appendix

17.1 Nagoya Test Track



17.2 100L System Parameters

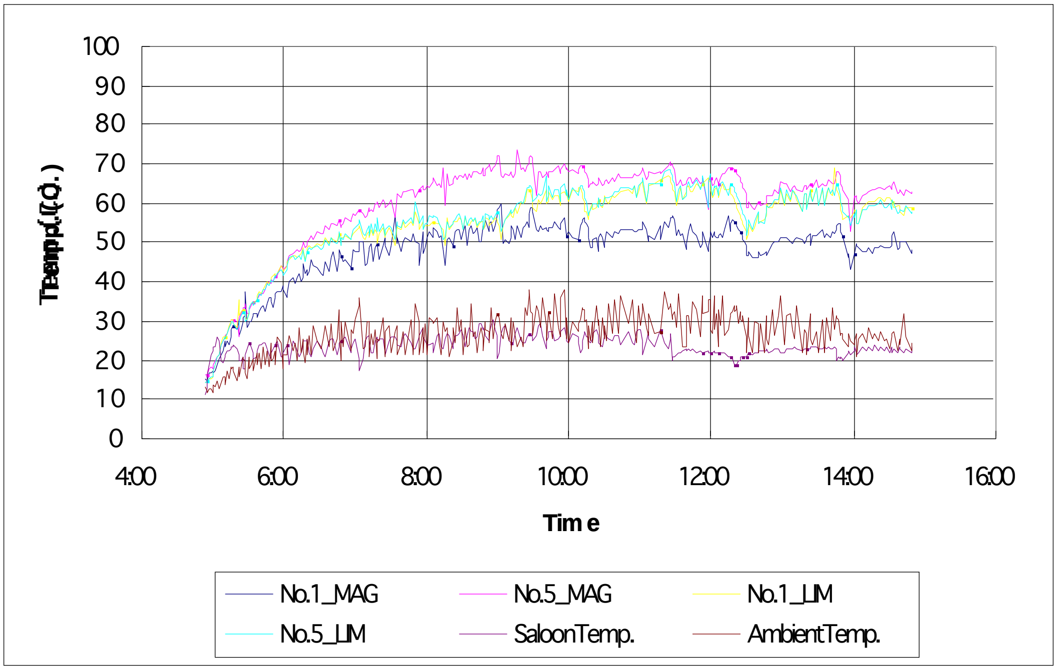
Vehicle Basic Specification of HSST -100L Test Vehicle	
Train	Two-car train
Length/Width/Height	30.0m/2.6m/3.45m/Train
Vehicle Weight	Empty:17.0 ton/car, Maximum:25.0 ton
Passenger Capacity	220 /train
Max. Acceleration	4.5 km/h/s
Service Braking	4.5 km/h/s
Emergency Braking	4.5 km/h/s
Suspension System	Flexiblemulti-module,5coupled-modules/car
Type of Levitation & Guidance	Normal conductive U-shaped attractive magnets for both levitation and guidance
Propulsion	10 Linear Induction Motors /car

17.3 Typical Test Scenarios and Traces

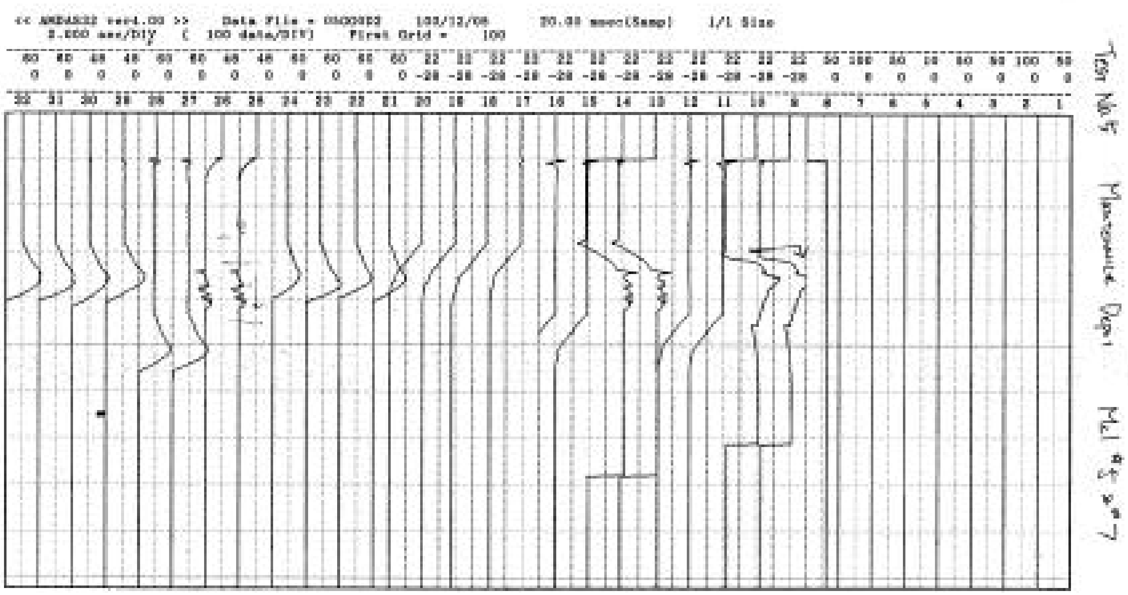
On-board Data Logging

Uneven Load Test

Typical Temperature Rise Trace



Typical Gap Trace



Typical LIM Input Current Traces (from LIM Failure Test)