ROLLINGSTOCK BOGIE ASSEMBLY AND WEIGHING STATION
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SUMMARY

Following a number of unexplained derailments of Electric Multiple Unit (EMU) Trains in Sydney and also the rapid settlement of the rubber springs installed on Tangara Cars, State Rail specified that all cars were to be weighed and balanced following bogie replacement. Research showed that although there were devices available throughout the world for weighing cars and bogies, these did not meet the requirements of State Rail or the maintenance workshops in achieving the desired result.

To meet State Rail specifications, MainTrain, which is contracted to State Rail for EMU Car Heavy Maintenance initiated a project to research and develop a bogie assembly and weighing station that would meet all production requirements and achieve specification.

A unique wheeling and weighing station for bogies has now been built and installed in the MainTrain Bogie Shop with excellent results, and has set the standards for accuracy and consistency in bogie balance. All cars now released from MainTrain meet State Rail Specifications in regard to weight and balance.

This paper presents a description of history behind the development of the machine, concept, design and manufacturing process, results of the review and potential benefits. The main conclusion of this work is an improved understanding of the weighing process, parameters to which the car weighing performance is sensitive and a basis for evaluating and manufacturing alternative designs.

1. INTRODUCTION

In Sydney the city transport system has an extensive fleet of double deck EMU cars operating on the City Rail network. The total fleet size of the EMU Fleet is 1468 vehicles comprising 450 Tangara cars, 773 Double Deck Suburban Cars and 245 Double Deck Inter City Cars.

The operating conditions can be severe as a large percentage of the track runs over hilly mountainous country, with many curves, some constructed for speeds of the Victorian era. Although much of the track is on concrete sleepers, there are still many timber sleepers in service. After heavy rainfall, which is prevalent in the Sydney area, many soft spots result in vehicles having to negotiate track irregularities.

After a number of unexplained derailments, the resulting investigations considered that one of the possible contributing factors could be car out of balance. City Rail instituted the installation of car weighing stations in their Service and Maintenance depots including those managed by MainTrain. This led to Tangara cars, which have a rubber primary suspension, being weighed at every bogie change. Subsequently other cars with helical primary spring suspensions were involved also in derailments of these particular cars were discovered to be out of balance. City Rail issued a mandatory requirement that all cars be weighed and balanced after repair or bogie change prior to going into service.

2. HISTORY

Prior to the introduction of the Tangara cars, EMU cars operating in NSW were weighed and balanced prior to introduction to commercial service. It was considered at that time that cars operating in the 8-9 tonne range at each wheel would not cause deterioration of the track structure.

An investigation of available information indicated that rail systems worldwide did not completely balance their lower speed passenger stock. TRTA in Tokyo, the benchmark operator adopted by MainTrain did not balance their cars.

Prior to the introduction of Tangara cars, the practice that was employed for weighing the cars when they first were designed, was to make estimates of the installed equipment and balanced prior to installation. When the first car of the series was built, the car was tested for load distribution to confirm the balance of the
This practice left the bogie out of balance to the extent of almost 500kg on the gearbox side due to the weight of the gearbox, gear wheel, oil, WN drive and pinion.

This factor has not been taken into account on NSW vehicles having metal primary springs and it appears that many railways throughout the world do not compensate for this type of imbalance. This situation had been accepted for 30 years for double deck cars, and for many single deck units dating back as far as 1925.

Cast bogies as shown in Appendix A manufactured prior to Tangara were constructed with spring seats varying by as much as 3mm in level. If the casting exceeded this dimension a compensating packer was welded in the low spring pocket.

Tangara bogies as shown in Appendix B were fabricated with the spring seats being machined to close tolerances. The primary springs are rubber, and the subsequent settlement has required the wheels to be balanced. This requirement has resulted in consideration being given to the remainder of the fleet and to solve the problem a weighing station was installed at the MainTrain depot to check the weight and balance of cars prior to release from the workshops after repairs.

The procedures developed included the installation of loose packings on top of the springs at each spring pocket, based on dimensions taken on a level stand. The springs had previously been calibrated and packing added to ensure that all springs were the same height such that the added packing compensated for frame variations. This method met with some success, but it was difficult to meet the balance figure of 700kg over one axle as required by State Rail. It was also difficult to accept this method in the production system, as incorrect bogies required removal from the cars for re-packing.

To address this issue, it was concluded necessary to weigh the bogies on their own prior to fitting to the car. It was agreed that a bogie weighing machine be installed in the bogie shop. When the design was further considered it was concluded that the weigh station should be built as an assembly station, hence being an integral part of the production line.

3. CONCEPT

Preliminary evaluation of several commercially available bogie weighing machines was carried out considering such parameters suitability for purpose, interfacing with the existing production system that included such parameters as suitability to the needs, interchangeability, interfacing with existing production system, cost and local support. In the following are the details of the evaluation:

- Most commercially available machines are designed to weigh the completed bogie, which including traction motors and other components. The drawback with this system is that the bogies are required to be stripped, re-packed to compensate for imbalance, re-built and re-weighed to test the corrected bogie. Such stripping and reassembly adds significant cost to the operation.
- These machines have limited options to facilitate different types of bogies and interchangeability only can be achieved after modification these machines were modified to suit.
- One of the important factors in the evaluation was the requirement for interfacing the new machine with existing production facilities. None of the commercially available machines were suitable to integrate with the existing production line for final assembly of bogies at the MainTrain Depot.
- Local support services were another important consideration, as any down time of the machine would have serious consequential effects on the cycle time to overhaul the rollingstock. None of the commercially available machines were locally manufactured and most of them had only limited local support services.

4. MAINTRAIN ALTERNATIVE DESIGN

Due to the non-availability of any suitable commercially available machines, MainTrain decided to custom design a assembly station which could pre-assemble the bogie, weigh the bogie and pre-finish the bogie assembly. The bogie wheel and weigh station was built to wheel the bogie frame excluding traction motors and other components, weigh the bogie, raise frame to pack springs with shims to compensate for imbalance and finish weighing. The following aspects were considered for finalising the concept design:

- Types of bogies to be weighed.
- Weigh without traction motors and brake cylinders.
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• Central pull type loading arrangement.
• Unique feature to raise and lower the bogie to fit packing.
• Central interlocking system to ensure safe operation of the machine.

It was considered that the positioning of the traction motors and brake cylinders balanced each other so there was no requirement for them to be fitted for weighing.

5. CONFIRMATION OF THE EFFECTS OF BOGIE WEIGHING WITHOUT TRACTION MOTOR AND OTHER COMPONENTS

The new concept of weighing bogies without traction motors, brake cylinders and other components previously had not been tested or documented. This concept was verified by carrying out simple dimensional tests. The tests were as follows:

Test – 1

• Every bogie type was assembled (with traction motors and other components) and under no load the actual compression of the primary springs was measured and recorded. Subsequently a measurable load was applied by the use of an existing hydraulic press and the actual compression of the primary springs was measured and recorded. The difference in compression was calculated and recorded.

• Every bogie in Test–1 was partially disassembled (removal of all traction motors and other components) and a measurable load equivalent to Test-1 plus additional load to compensate the weight of the removed components was applied. The actual compression of the primary springs was measured and recorded.

• The compression of the springs has a direct relationship to wheel loading. It was noticed that there was little difference in the compression lengths between the two tests. The tests actually confirmed that weighing of bogies excluding traction motors and other components was possible and the results were reasonably close to each other.

6. DESIGN PROCESS

Design of the wheel and weigh station was based on the existing State Rail bogies that were overhauled at MainTrain. Following are the key reasons for the new concept:

1. Bogie assembly and weighing station
   • Assembly and weighing station rather than weighing station only.
   • Centre pull type design to ensure equal loading at the point of loading and to simulate the car setup.
   • Different wheelbases and sizes of the bogies.
   • To accommodate different types of axle box arrangement.
   • To have capacity to load bogies at varying loads depending on the type.
   • To accommodate both Cast and Fabricated bogies.

2. Fabricated main structure for weighing
The Weighing Station was fabricated within the centre structure as shown above and was designed to take up any residual stress. The centre structure was also designed to ensure that there is no effect of deflection on the main rail during the load cycle. The material used for the main structure is a 700WB115-welded beam and this was selected for its high moment of inertia about the x-x axis. The construction was such that the entire imposed load from the load applicator was transferred to the bogie wheels, not through the main structure but through an inner frame, which when deflected did not affect the weighing system load cells located on the rails attached to the main framework. This section also enabled the bogies to pass over the various elements of the machine without interference.

7.1 Principle of Loading

3. Load transference beam

The load transference beam was freely suspended and held by the load applicator to facilitate the lowering and raising of different types of bogies. The load transference beam was coupled to the load cylinder to apply the required load at the loading point as shown in the figure above.

The load applicator was capable of acting as a constant load upon the bogie. Any change in deflection of the bogie suspension would automatically be compensated by the load applicator, whether that compensation required a raising or lowering of the applicator. Once loaded, such changes in suspension height were not likely to be greater than ±5mm.

The load applicator applied its force vertically at the nominal bogie center. The applicator applied the vertical force to the transference device through the self-aligning connection. The purpose of the lateral movement of the applicator and this self-aligning connection was to apply only vertical forces to the bogie. The transference device was located on the bogie via the center pinhole, to the load cylinder and locating on the side-bearing or air spring seating.

The force applied to the bogie by the load applicator was to be within the range of 0 to 30000 kgs in steps. Once applied, the load was maintained within ±1% of the pre-set load. A pre-selector control was arranged such that any applied load could, by changing the selector setting, be varied throughout the specified range of loading. However, on removal of the load at the end of the test any setting on the pre-selector was cancelled back to minimum loading to prevent operator error causing an overloading of any subsequent bogie.

7.2 Automatic Wheel Base Adjustment System

4. Wheel base positioning system

An important feature of the wheeling and weighing station was that the system could position the wheelset / bogie to the required wheelbase dimension for assembly and weighing. The entire system slides on linear bearings and these bearings require minimum maintenance. Provision was made for individual fine adjustment of each of the adjusting systems to allow for variation in manufacturing tolerances, such allowance being ±2mm of nominal wheelbase. This fine adjustment was to ensure that by centring the adjusting system to the axle centre, only vertical forces were created between the wheel and the load cells.
7.3 Axle box / Journal box location system

The location system in the wheeling station was built around a combination of linear bearings and a low-pressure hydraulic system. The low-pressure hydraulic system prevented any damage to the axle box and bearing, the advantage of this was to limit the applied force to 800N. When locating the bearing boxes they could be at different angles so the location system allowed the location fixture to be manually retracted and re-applied at all four stations.

The location fixture was held in place by the hydraulic system until a bogie was lowered onto the bearing boxes. The hydraulic system allowed the fixture to collapse under the weight of the bogie whilst keeping the bearing boxes aligned. One location fixture was designed to cater for all types of axle boxes.

7.4 Frame Lifting Device

The correction of bogies for any imbalance required balance packing to be inserted on top of the primary springs. The frame-lifting device consisted of four cylinders, which were simultaneously operated to raise and lower the bogie frame for packing. This operation was critical in achieving consistency in the weigh results and any wrong operation would result in unacceptable inaccuracies.

7.5 Weighing System

The weighing system consisted of four load cells; the load cells were continuous rail track strain gauge types. This system was developed and installed by Rail Infrastructure Corporation. Measurement accuracy was around +/- 10kgs. Strain gauges measured the strain in the rail under load and a computer system converted that to actual wheel loads in kgs. This system was similar to MainTrain’s car weighing system.

7.6 Computer System

A fully integrated computer system displayed and printed the weighing results with calculated suggested packing for adjustments. The software incorporated all combinations of bogies with a completely integrated database, which captured weighing information of each bogie for future reference and analysis. The hardware had a built-in feature for future upgrading to convert existing manual control to a computerised control system.

7.7 Interlocks

Using a (PLC), many interlocks were introduced to prevent accidents or damage to the machine, some of the functions of the interlocks were:
The bogies could not be moved until all cylinders, rams, fixtures and locks were disengaged.

Loading could not commence until the bogie was locked in place.

Loading could not commence until the load bar was locked in place.

The bogie could only be loaded to a preset limit.

Inadvertent use of the machine was not allowed.

8. MANUFACTURE

Manufacture of the wheel and weigh station was a joint project between MainTrain and TYSCI Technologies (a local Australian Company). From the initial consultation, several manufacturing designs were produced in sketch form to evaluate each design’s merits. These were compared with the specifications and finally one was selected as the preferred option. Upon finalisation of the manufacturing design, the assembly drawings were produced and from this the basic construction was generated. Some of the reasons for selecting this manufacturing design were: ease of manufacture, cost, simplicity of operation, reliability and reduced maintenance costs. One of the critical factors to be considered for this one-off design was risk assessment and risk reduction.

The wheel and weigh station was manufactured as three separate sections (wheeling station, weighing station and finishing station). The main reason for three-piece construction was to test the functionality of each section individually and also to facilitate transport and installation.

Positioning the bogie on the machine in both the wheel assembly and weigh station areas was done using a digital proportional amplifier driving dual hydraulic cylinders through proportional directional valves. This was designed to give accurate positioning and it could position the bogie within 0.5 mm. Each cylinder in turn moved a frame, which locked the wheel in position by a hydraulic applied lock lever.

The weighing system was fitted to the weigh station after the entire assembly was installed and leveled at MainTrain. This reduced any risk of damaging the weighing equipment during transportation and installation.

The wheel and weigh station had in-built safety interlocks to minimise any risk associated with safety hazards to the operator and also to avoid any damage to the station when it was in operation.

The workstation was custom built to MainTrain’s requirements and was unique in design with many innovative devices such as PLC’s, dual hydraulic system and a completely integrated interlock system. Most importantly the entire station was manufactured in Australia using locally available components. 80% of the parts / components were standard shelf items available in Australia.

Using hydraulics in this machine had many advantages and unique features as set out below;

- Accurate positioning through an analogue feedback circuit.
- Steady movement and speed control settings through the digital amplifier.
- By using two cylinders in series one axle set or bogie could be accurately positioned.
- The low-pressure hydraulic system at 50 bar used a pressure compensated piston pump.
- The loading system used a second pressure compensated piston pump at 210-bar pressure.
- Each pump delivery was filtered to 10 microns for system reliability and longevity.
- Heat generation and noise levels were within OH&S recommendations.
9. INSTALLATION AND TESTING

9.1 Installation

Location of the machine was critical to production and was installed in an area where the dependency on the overhead crane was minimal. The station was positioned close to a support to ensure that the suspended floor construction in the bogie shop supported the weight of the machine and also to minimise the effect of any vibration transferring to the weigh station.

9.2 Testing For Performance

All types of bogies were tested in the wheel and weigh station for operational and engineering requirements. Minor modifications were carried out to improve the performance. Weighing analysis as shown in the graphs indicate the improvements achieved during the testing phase.

9.3 Review By Consultant

After installation and testing, an independent consultant reviewed the entire wheel and weigh station procedure. The weighing results were also analysed by the consultant to ensure that they were in accordance with the requirements of State Rail specification.

10. RESULTS

Graphs in Appendix D and E indicate the accuracy of the weighing process for cast and fabricated bogies. The weight difference between wheels on an axle is the critical measurement; this difference peaked at 250 to 300kgs in the beginning and started to reduce over a period of time. Graph in Appendix C shows the relative reduction in the number of weighings required over the same time period. The reduction in the difference followed minor modification to the procedure and the process. Some of the minor modifications were:

- A wider contact area was established at the point of loading to ensure that the bogie was rigid and simulated the setting under a car.
- Some of the bogies were found to have casting defects in the pocket and these bogies were machined to suit.

11. BENEFITS

- The design of the machine meets and exceeds all operational, engineering and safety requirements.
- Bogies currently being balanced by the use of wheel and weigh station are within 0.5% of the acceptable tolerance for weight differential between wheels on an axle.
- Owing to the provision of balanced bogies, there has been a greater than 50% reduction in the cycle time for weighing cars.
- Following the introduction of the wheel and weigh station, the car weighing data shows that cars are consistently achieving an average imbalance not more than 2% between wheels on one axle. This is 50% better than the State Rail specification.
- A combined benefit in terms of cost savings is estimated to be around 100,000 dollars per year.

12. CONCLUSION

In conclusion, the main objective of improving car weighing process was achieved with excellent results. The car weighing results are now consistent and well within the State Rail specifications in regard to weight and balance of cars. These improvements will help in minimising the effects of out of balance cars being a contributory factor in derailments.

In future, analysis of the data being collected shall determine the need for car weighing. Cars fitted with completely balanced bogies, will only require the car and air bag heights to be adjusted to ensure balanced wheel loads.
13. **ACKNOWLEDGMENTS**

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14. **REFERENCE**

1. Procedures for preparing and weighing of cars on Weighbridge, State Rail Engineering Instruction – 175.


15. **APPENDICES**

Appendix A - Cast Bogie Details

Appendix B - Fabricated Bogie Details

Appendix C - Graph, Data on Repeat Weighing per Bogie

Appendix D - Graph, Cast Bogie - weight difference between wheels on an axle.

Appendix E - Graph, Fabricated Bogie - weight difference between wheels on an axle.
CAST BOGIE DETAILS

Legend:
1. Bogie main frame
2. Drive gear
3. Traction motor
4. Gear box
5. Brake cylinder
6. Brake cylinder with spring parking brake
7. Brake rigging
8. Intermediate beam
9. Air spring
10. Primary spring seat
11. Secondary spring seat
12. Torsion bar shock absorber
13. Torsion bar shock absorber
14. Torsion bar spring
15. Torsion bar spring
16. Brake shoe
17. Brake shoe
18. Brake shoe
19. Brake shoe
20. Brake shoe
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22. Brake shoe
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31. Brake shoe

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APPENDIX B

FABRICATED BOGIE DETAILS

- AIR SPRING
- EMERGENCY RUBBER SPRING (ON CAR)
- ANTI-ROLL BAR ASSEMBLY
- GEAR UNIT
- FRAME
- BRAKE RIGGING
- SERVICE BRAKE
- WHEEL & AXLE ASSY
- PARK BRAKE
- PRIMARY SPRING
- JOURNAL BOX
- TRACTION BEAM
- TRACTION ROD
- LATERAL DAMPER
- HEIGHT ADJUSTING LINK
- BRAKE PIPING
- LEVELLING VALVE

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APPENDIX C

CAST & FABRICATED BOGIE - DATA ON REPEAT WEIGHING PER BOGIE

APPENDIX D

CAST BOGIE - WEIGHT DIFFERENCE BETWEEN WHEELS ON AN AXLE
FABRICATED BOGIE-WEIGHT DIFFERENCE BETWEEN WHEELS ON AN AXLE

Weight in kgs

WEEK1  WEEK4  WEEK7

Time Period

Axle1  Axle2