3. Theory and Equipment

3.1. Pipe Equations

To analyse the speed of a pressure wave a control volume that moves with the wave is chosen as shown in Figure 36 (Gerhart 1985)

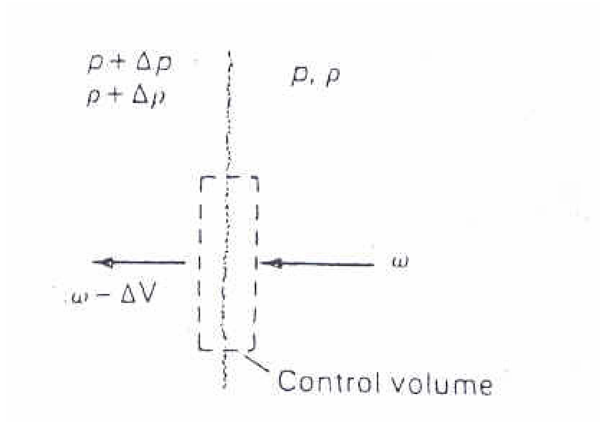

Figure 36: Compression wave in a fluid (Gerhart 1985)

Since the wave is very thin, it is assumed that it is has no thickness so all the areas of the front and back faces of the control volume are equal and the volume is zero. Then the continuity equation for a control volume is:

$$\dot{m} = \rho A\omega = (\rho + \Delta\rho)A(\omega - \Delta V) \qquad \textbf{(3.1)}$$

Where $\dot{m}$ = mass flow rate, ρ = density, A = cross sectional area, ω = velocity of the wave, ΔV = velocity of the fluid behind the wave and p = pressure of the fluid. Then cancelling A and solving for ΔV gives:

$$\Delta V = \omega\left(\frac{\Delta\rho}{\rho + \Delta\rho}\right) \qquad \textbf{(3.2)}$$

Applying the linear momentum equation to the control volume as the ‘sides’ of the control volume are vanishing small, the only force on the control volume is due to the pressure on the inlet and outlet faces.

$$\sum F_x = pA - (p + \Delta p)A = \dot{m}[(\omega - \Delta V) - \omega] \tag{3.3}$$

Substituting for $\dot{m}$ and solving for Δp will give:

$$\Delta p = \rho\omega\Delta V \tag{3.4}$$

An expression for wave speed is obtained by substituting **(3.2)** into **(3.4)**

$$\omega^2 = \frac{\Delta p}{\Delta\rho}\left(1 + \frac{\Delta\rho}{\rho}\right) \tag{3.5}$$

An isentropic (adiabatic) process is assumed because there is minimal opportunity for heat transfer to or from the fluid as it passes through a thin wave. The speed of sound is therefore defined by:

$$c^2 \equiv \left.\frac{\partial p}{\partial \rho}\right)_s \tag{3.6}$$

Where c = speed of sound

For an ideal gas, an isentropic process obeys the equation:

$$\frac{p}{p_{ref}} = \left(\frac{\rho}{\rho_{ref}}\right)^k \text{ and so } \left.\frac{\partial p}{\partial \rho}\right)_s = k\left(\frac{p}{\rho}\right) = k\mathrm{RT} \tag{3.7}$$

Where *k* the adiabatic constant, characteristic of the specific gas =1.4, R = gas constant for air = 287.04 J/kg-K. T = absolute temperature in Kelvin.

The speed of sound in an ideal gas is calculated by:

$$c = \sqrt{k\frac{p}{\rho}} \tag{3.8}$$

or

$$c = \sqrt{k\mathrm{RT}} \tag{3.9}$$

3.1.1 Sonic Velocity Calculation

- When R = the gas constant for air = 287.04 J/kg-K.
- T = the absolute temperature in Kelvin.
- *k* = the adiabatic constant, characteristic of the specific gas =1.4

Using the above parameters, then the speed of sound when using equation **(3.9)** with dry air and at 32^0 C will be 350.18 m/s.

3.1.2 Calculation of pipe length for QR VSAL/S wagons.

From Figure 37 when a QR VSAL has a length of brake pipe with a measurement along the centre of the pipe, called a centreline method of length and has been calculated from the following:

VSAL Coal Wagon 106 Tonne is 14.936 m in length over headstocks, the dimensions in Figure 37 shows the pipe length in mm.

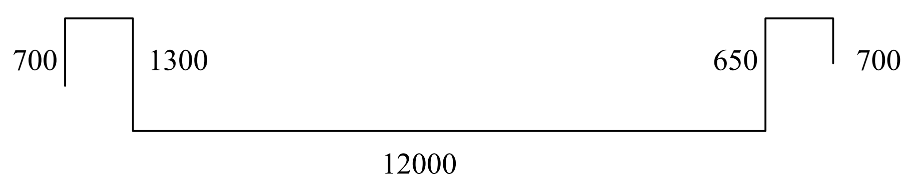

Figure 37: Centreline length of a QR VSAL/S 106t coal wagon.

Drawings supplied by QR for piping arrangement dwg. No. A0-33765

- For a VSAL when the length by centreline method is = 6 X 90^0 Pipe Bend (0.3 m radius) = 2.83 m and then +0.7 m (pipe) +1.3 m (pipe) +12 m (pipe) +0.65 m (pipe) +0.7 m (pipe) = **18.18 m.**

- For a VSAS when the length by centreline method is = 6 X 90^0 Pipe Bend (0.3 m radius) = 2.83 m and then + 0.75 m (pipe) +1.3 m (pipe) + 12 m (pipe) +0.45 m (pipe) +0.75 m (pipe) = **18.08 m.**
- The total centre line length of brake pipe for the two wagons is **36.26 m.**
- The inclusion of the hose coupling lengths between each wagon (4 x 0.7 m) will bring the overall length to **39.06 m.**

[Note] The overall centreline length of a train brake pipe is used in propagation rate calculations.

3.2 Equipment

To be able to investigate the brake application delays without a long train to use for experimental purposes, a laboratory setup of a train brake pipe was used. The test rig, because of project expenditure constraints, only had the use of 4 control valves and with appropriate pipe work was made in the same configuration as a coupled pair of wagons. The setup was to examine in detail the pressure in the brake pipe at different locations along the pipe while and after different brake reductions were made. Different sized brake pipe exhaust chokes were used to simulate a reduction rate in the experimental rig similar to results from train tests results.

For the experiments, complete sections of brake pipe from two coal wagons of the VSH type were utilised in a configuration as shown in Figure 39. The brake pipe also included nine (9) bends of 90^0 with radius of 200 mm and two flexible hose couplings, from the VSH installation. A further 83 meters of pipe with sixteen (16) bends of 90^0 with a radius of 100 mm and with four flexible hose couplings were utilised to give a combination long enough for the inclusion of four control valves. The total centreline length of the brake pipe was 120 meters. Pipe diameter was

0.0345 m (32 NB heavy gal. pipe) and the volume of the pipe was 112.17 litres. A 37 litre reservoir was fitted to the end of the pipe.

For the series of experiments completed, the 1st control valve is connected to the brake pipe via a tee junction. Positioned on one side of the tee junction is an exhaust, which has an exhaust choke for controlling the brake pipe flow and hence the rate of brake pipe pressure reduction. The other side of the tee is connected to the remainder of the brake pipe. At a distance of 37 meters from the first control valve a tee to the pipe connects a second control valve. A third control valve 37 meters from the second control valve is connected by using another tee to the pipe and a fourth tee connects the fourth control valve at a further distance of 43 meters. The pipe extends for a further 3 meters and is connected to a reservoir of 37 litres capacity. The 37 litre reservoir was added to the brake pipe to reduce reflection of pressure waves. An extra 6 meters of pipe was fitted between the third and fourth control valve because of space limitations within the lab area for positioning of control valves.

Positions of the pressure transducers on the brake pipe as shown in Figure 39 and on the brake equipment were as follows:

- Transducer P1 fitted at the brake pipe side of the main diaphragm on 1st control valve
- Transducer P2 fitted at the brake pipe side of the main diaphragm on 2nd control valve
- Transducer P3 fitted at the brake pipe side of the main diaphragm on 3rd control valve
- Transducer P4 fitted at the brake pipe side of the main diaphragm on 4th control valve
- Transducer P5 at the brake pipe tee to the 1st control valve
- Transducer P6 fitted after the tee to the 2nd control valve

- Transducer P7 fitted after the tee to the 3rd control valve
- Transducer P8 fitted 3 meters after the 4th control valve

A data acquisition system taking samples at 250 /s was used to record pressures.

From the data obtained after running the experiment, the velocity of the waves, the rate of reduction and the size of the reduction as it travels along the pipe could be calculated.

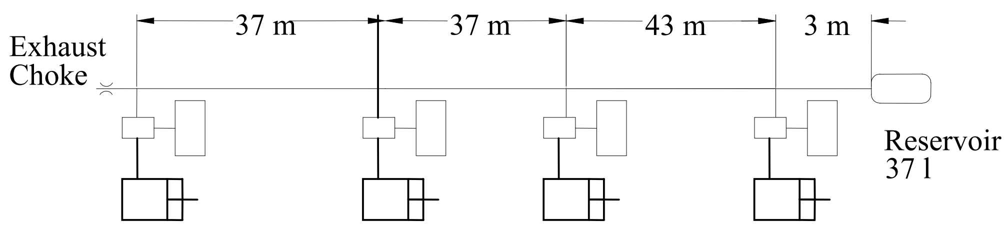

Figure 38: Schematic of brake pipe test rig setup.

Equipment used during testing:

- 120 meters of 32 mm NB heavy duty galvanised pipe
- Westinghouse WF4 Control valve # NWFF302
- Westinghouse WF4 Control valve # NWFF303
- Westinghouse WF4 Control Valve # NWFF304
- Westinghouse WF4 Control valve # NWFF305
- ‘K' type thermocouples.
- National Instruments DAQ comprising of PXI 1002 General purpose chassis.

  NI PXI-8175 Pentium III Embedded Controller for PXI.

  NI PXI-6040E 500 kS/s (1-Channel), 250 kS/s (Multichannel), 12-Bit, 16 analog input multifunction DAQ
- Sh 68 _ 68 EP 1m shielded cable.

- CB_68LP terminal block.
- WABCO (SETRA) transducer Model 207 pressure range 0-100 PSIG, Excitation 12-28 VDC, Output 0.1-5.1 VDC, Accuracy ±0.13% Full Scale (RSS method)
- Druck DPI 705 Digital Pressure Indicator
- Labwindows CVI 5.0 was used with ANSI C for the programming

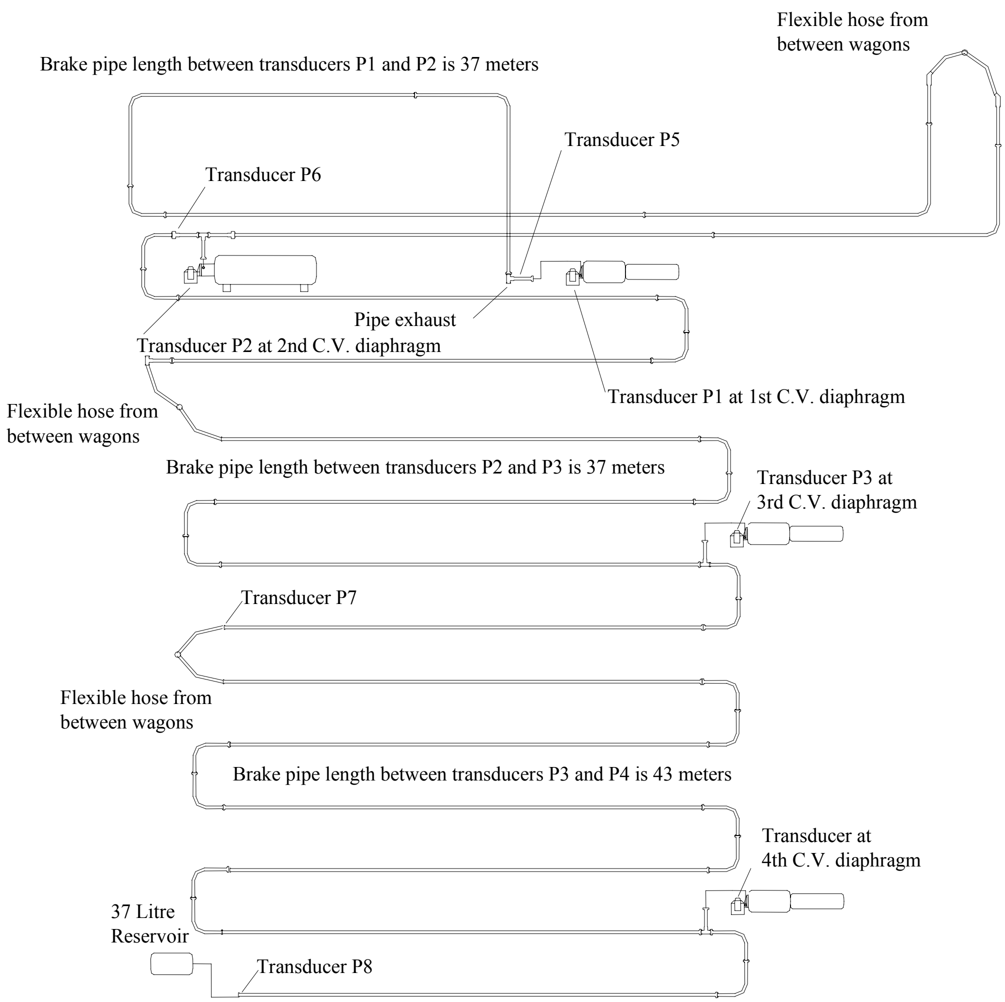

Figure 39: The experimental brake pipe rig and transducer locations.

The temperature of the air in the pipe at the time of testing was 32^0 C, humidity approximately 55%.

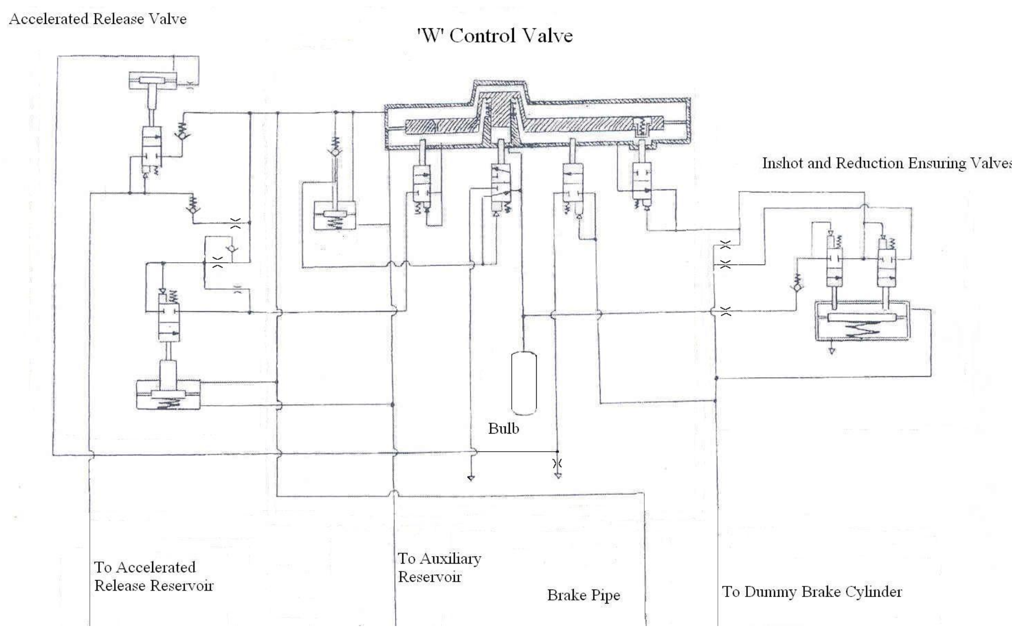

Figure 40: 'W' control valve schematic

The four 'W' style control valves used on the test rig are typical of the schematic shown in Figure 40 and of the diagrammatic view as shown in Figure 41. The both figures show the features and functions that are added to a standard valve shown in Figure 17.

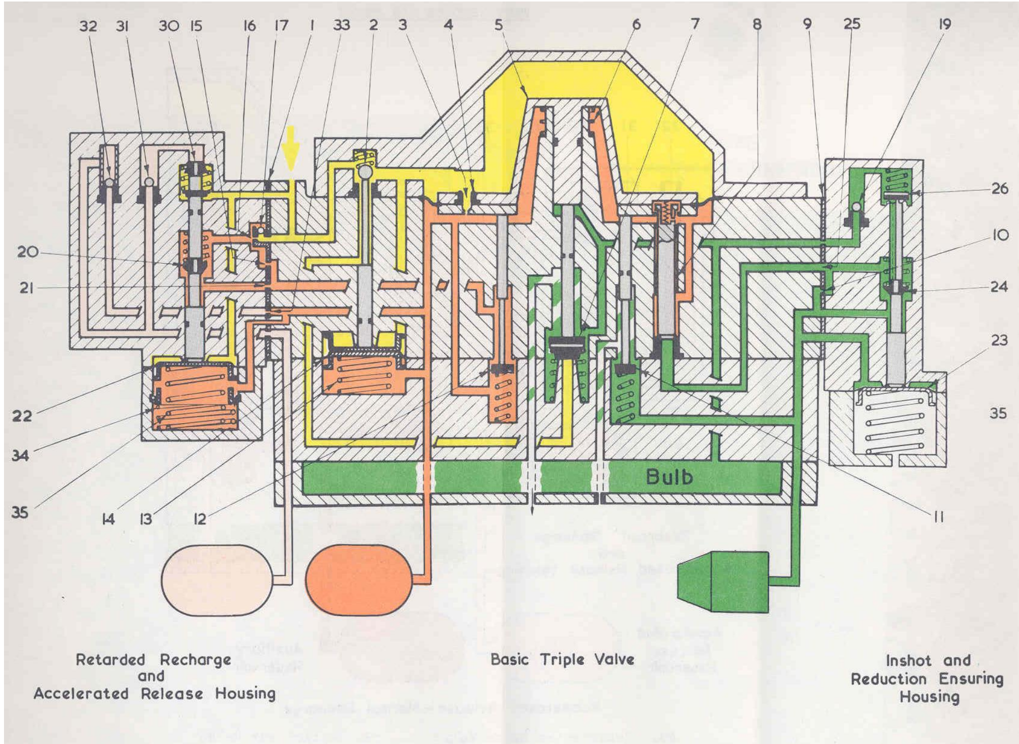

Figure 41: Diagrammatic view 'W' control valve

3.3 Data Acquisition and Processing

Transducers used had a rate of 137.89 kPa/volt. Using 12 bit resolution, pressures could be resolved to 0.6733 kPa. This gave a step like appearance to plotted data when small changes are highlighted in results.

The Wabco 207 pressure transducers were checked and calibrated by comparison with the Druck 705 pressure indicator.

While channels were scanned once every 0.004 seconds inter-channel time skew was minimised by a channel to channel time of 10^{-5} seconds.

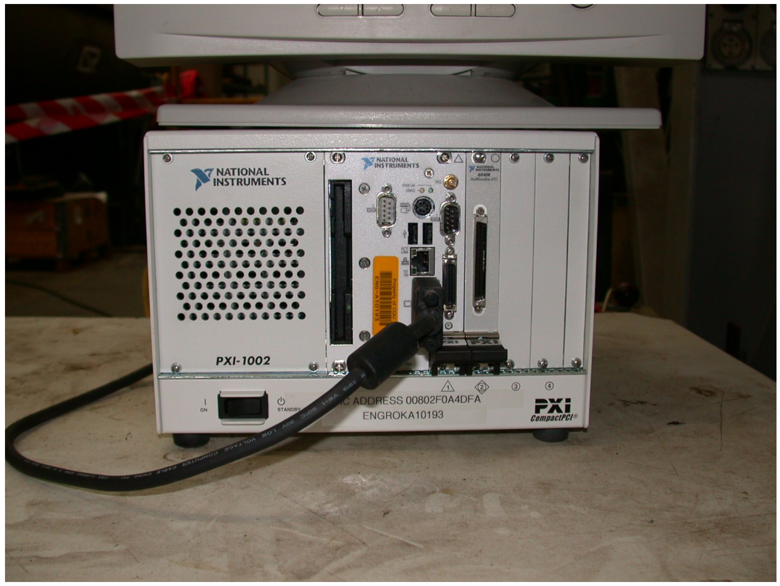

Figure 42: National Instruments DAQ

Figure 43: Sh 68 _ 68 EP shielded cable, CB_68LP pin terminal block.

Figure 44: Druck 705 pressure indicator.

4. Experiments and Results

4.1 The rate and size of reduction of the gulp in a brake pipe

4.1.1 Introduction

The purpose of this experiment is to measure the propagation speed compared to sonic velocity and size of a gulp in a short length of experimental brake pipe. The experiments are in two parts, the first part measures the effects of the bulb action in the brake pipe of 120 m in length from operation of one control valve. The second part measures the effects of the bulb action in the brake pipe when four control valves are operated within the same 120 m of brake pipe.

Control valves fitted to wagons are controlled by the pressure of the air in the train brake pipe. A reduction of pressure of the air in the brake pipe has the effect of activating a brake application. The reduction in pressure is initiated by exhausting air from the front end of the brake pipe, usually via a valve in the locomotive. The precise instant that a control valve is activated is determined by the instant when a specified pressure difference between the brake pipe pressure and the auxiliary reservoir pressure of that control valve is reached.

From gas dynamics theory it is known that a pressure disturbance wave from the sudden opening of a valve at one end of a pipe will be propagated at sonic velocity through the gas. While the pressure wave corresponding to the initiation of a pressure reduction in the brake pipe propagates at sonic velocity, the pressure reduction that is sufficient in size to activate the control valve is limited by the actual gas flow exhausting from the pipe. As the pressure reduction propagation distance becomes longer the pressure wave front diminishes in size and therefore the pressure reduction of adequate size to operate the control valve takes longer to occur.

In Australian designs, additional exhaust gas flows are initiated at each control valve by the use of a cavity or volume known as the "bulb" or the quick service volume. The opening of the brake pipe to connect to this volume creates a further pressure disturbance wave that assists the exhausting gas flow and locally increases the rate of pressure reduction available to the next valve. In the first of experiments in this chapter, the pressure wave developed by the quick service volume of a control valve in a wagon brake pipe is measured and analysed along a pipe by using pressure transducers and data acquisition.

4.1.2 Equipment

For measurements of the pressure reduction rate in a brake pipe, the equipment used is detailed in section 3.2 and the configuration is as shown in Figure 39.

4.1.3 Method

The air in the pipe was compressed to 500 kPa and allowed to stabilise. Air was then exhausted through the exhaust choke. Choke of diameters of 2 mm, 1.5 mm, 1.2 mm and 0.91 mm were selected by testing various sizes of chokes then measuring the reduction drop rate of each choke. The choke diameters were then enlarged or new smaller ones made so the results would compare favourably with drop rates observed in train line data. The selection of chokes diameters allowed the discharge from 120 meters of test rig brake pipe to give a pressure drop similar to that seen at either:

- The 21st wagon with head and mid locomotives shown in Figure 45
- The 41st wagon with head and mid locomotives shown in Figure 45.
- The 92nd wagon with only head end locomotive power as shown in Figure 46

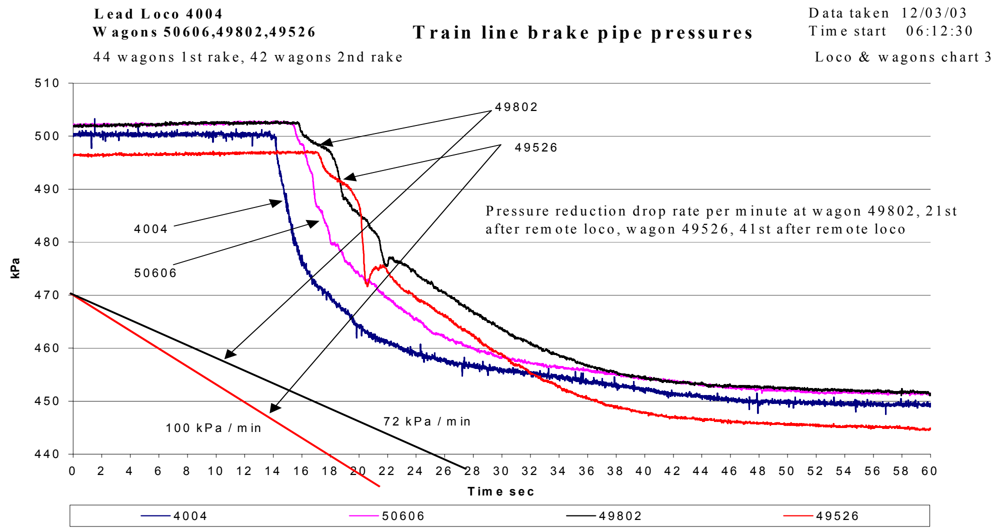

Figure 45: Brake pipe reduction. (CQU RA1.1 tests 2003)

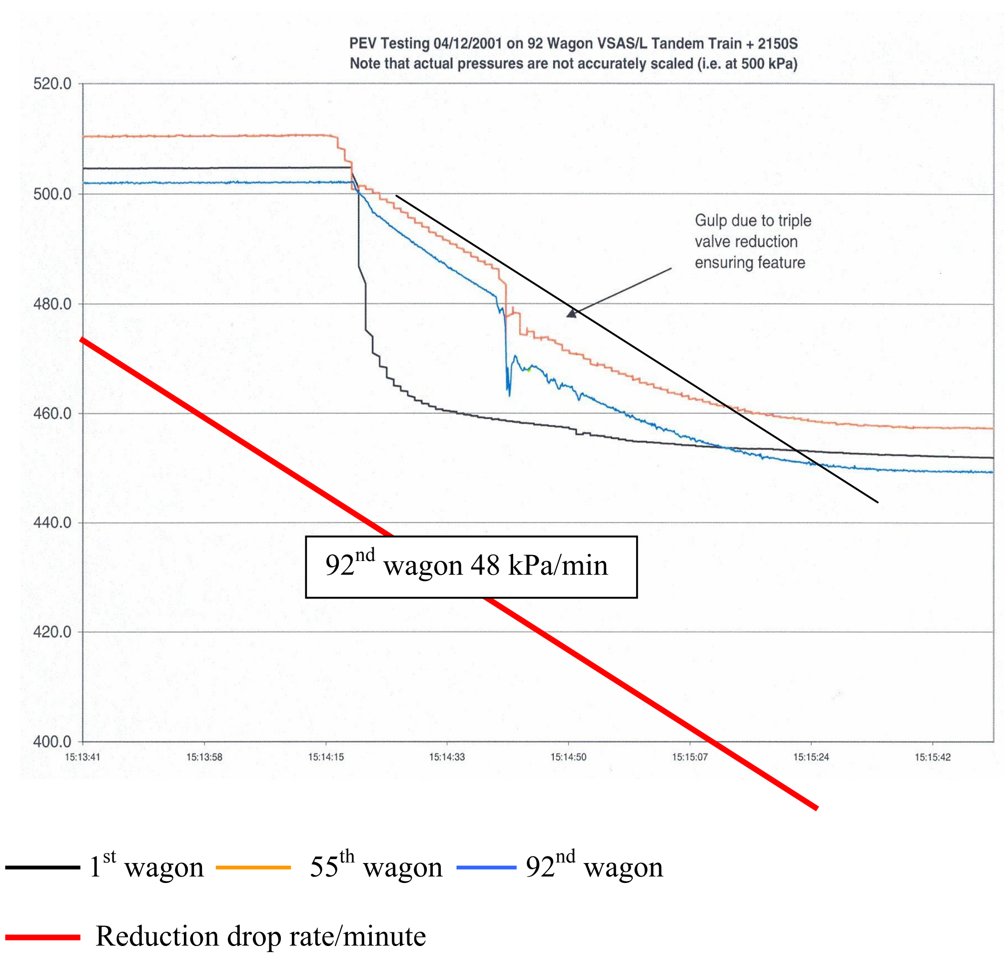

Figure 46: Reduction rate of a 92 wagon train. (Queensland Rail, 2001)

The uncertainty in measurements and calculations using the equipment and transducers is quantified as follows:

Using 250 samples per second this gives one sample every 0.004 seconds. (1/250)

With a pipe length of 120 meters then this gives 0.00083 m. (0.1/120)

Then a variance of +/- 0.00083 meters and +/- .004 seconds can be used.

A time period over the 120 m is 0.340 seconds as seen in Figure 48.

$$\Delta Z = Z\sqrt{\left(\frac{a}{A}\right)^2 + \left(\frac{b}{B}\right)^2} \qquad \textbf{(4.1)}$$

Where a = .0083 meters

A = 120 metres

b = 0.004 seconds

B = 0.340 seconds

Z = 352 m/s

$\Delta Z =$ 4.14 m/s

The velocity of 352 m/s from Figure 50 and an uncertainty of +/- 4.1 m/s therefore indicate sonic velocity in the range 347.9 m/s to 356.1 m/s.

4.1.4 Results

The results shown in Table 5 and in Figure 48 are from a brake pipe length of 120 meters and with 1 control valve. The brake pipe reduction rate was 54 kPa/min by using an exhaust choke of 1.2 mm diameter. The graphs show the brake pipe pressure being steadily reduced until the first control valve operates. After the valve operation the brake pipe air pressure (P1) measured at the control valve sharply reduces from 488.1 kPa at time of 13.9 seconds as the filling of the bulb from the brake pipe pressure in the cavity above the diaphragm has commenced. The pressure at P1 drops rapidly to 430.2 kPa at 14.1 seconds. When the bulb volume has begun to be filled, the brake pipe air pressure at P1 increases from a pressure of 430.2 kPa and is then stabilised at a pressure of 486.7 kPa at time of 14.7 seconds. The sharp reduction shown and the returning to a steady reducing pressure can be called a 'local gulp' and can best be seen in the brake pipe pressure of the control valve measured in the cavity above the diaphragm in the control valve. The gulp visible in the brake pipe is modified by the restrictions to flow in the branch pipe and passageways that connect to the cavity above the control valve diaphragm. The local pressure reduction in the brake pipe measured at P5 shown in Figure 48 is the final pressure drop produced in the pipe from the control valve bulb function. The 'local gulp' of brake pipe pressure seen at the control valve has been reduced to only a comparatively small reduction in pressure in the brake pipe. The smaller local reduction of the pressure in the brake pipe has been a result of the restricted mass flow through the branch pipe and passageways of the control valve from the larger volume of the brake pipe. It is this local reduction in the brake pipe pressure that propagates along the brake pipe and is shown at transducers P6, P7 and P8. The local reduction in pressure in the brake pipe is also known as the brake pipe gulp or more commonly the 'gulp' as shown in Figure 46.

Table 5: Brake pipe pressures from a single control valve operation.

Time (s)	P1 (kPa)	P5 (kPa)	P6 (kPa)	P7 (kPa)	P8 (kPa)	Comments
0	499.6	499.5	499.8	500.3	500.3	Pipe at stabilised pressure
2.8	498.9	497.7	499.5	498.9	498.9	Start of B.P. exhaust
13.9	488.1	489.7	489.4	489.5	489.5	Start of C.V. application
13.94	481.4	488.3	489.4	489.5	489.5	Start of pressure wave at P5
14.03	430.2	486.3	489.4	489.5	488.8	Bottom of 'gulp' at P1
14.06	436.9	484.9	488.7	489.5	489.5	Bottom of pressure at P5
14.28	478.7	486.9	487.4	486.1	488.8	Start of pressure wave at P8
14.41	481.4	486.9	488.1	486.8	485.5	Bottom of pressure at P8
14.68	486.7	486.9	488.1	486.8	486.8	P1 stabilising with P5

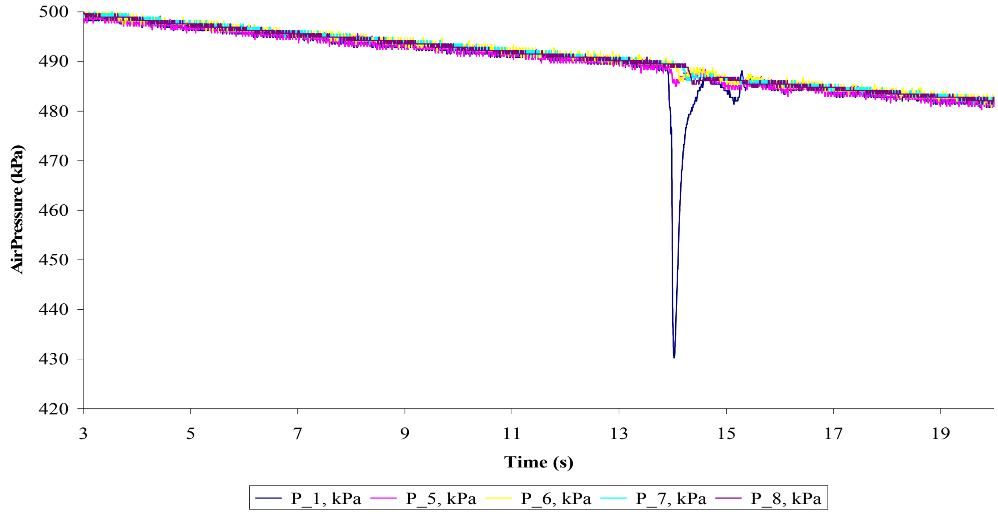

Figure 47: Pressure reduction rate of 54kPa/min and a single valve operation.

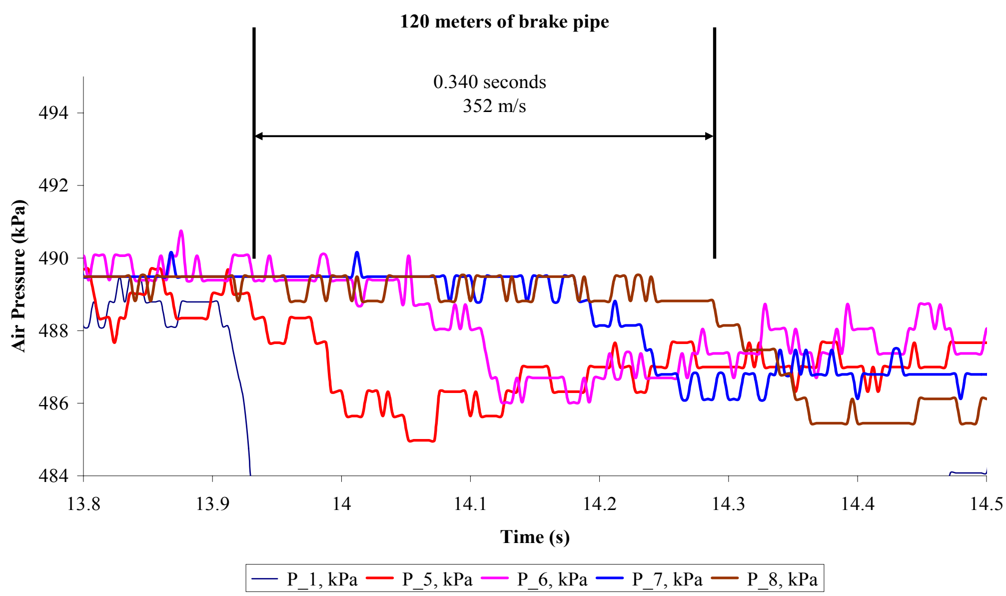

Figure 48: Gulp propagation resulting from the single valve operation.

The results shown in Table 6 and in Figure 49 and Figure 50 are from a brake pipe length of 120 meters and with 4 control valves. The brake pipe reduction rate was 48 kPa/min and was achieved by using an exhaust choke of 0.91 mm diameter. The graph in Figure 49 shows the brake pipe pressures being reduced after the exhaust choke is opened to atmosphere, leading to a steady reduction of 48 kPa / min. The four control valves each show a ‘local gulp’ measured at the cavity above the diaphragm of each valve. The graph in Figure 50 shows the local pressure reduction produced from each control valve bulb operation and the size of the local pressure reduction as it travels along the pipe. The results from Table 6 show the same characteristics of a 'local gulp' as shown in the previous table although with different results for the local pressure reduction in the brake pipe at each transducer location.

Table 6: Brake pipe pressures from 4 control valve operation.

Time (s)	P1 (kPa)	P5(kPa)	P6 (kPa)	P7 (kPa)	P8 (kPa)	Comments
0	500.2	500.5	500.2	500.3	500.3	Pipe at stabilised pressure
1.92	499.6	499.8	499.5	500.3	499.6	Start of B.P. exhaust
18.14	486.1	486.9	487.4	487.5	487.5	Start of C.V. application
18.17	478.7	486.9	487.4	487.5	486.8	Start of pressure wave at P5
18.31	445.1	483.6	486.7	488.1	487.5	Bottom of pressure at P5
18.51	476.7	485.7	484	484.1	486.9	Start of pressure wave at P8
18.75	480.1	481.6	483.3	483.7	478.7	Bottom of pressure at P8

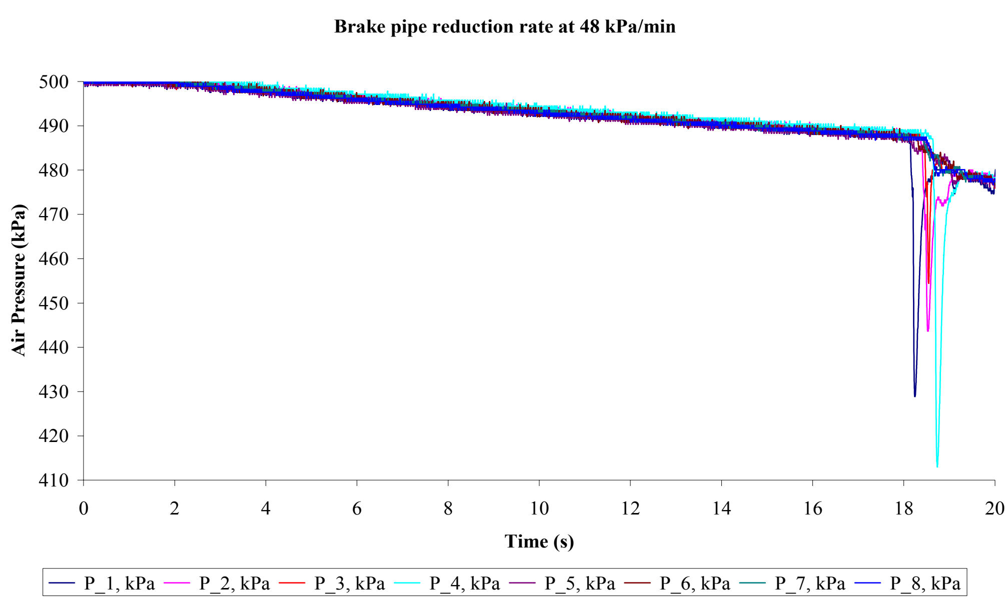

Figure 49: Pressure reduction rate and the operation of four valves.

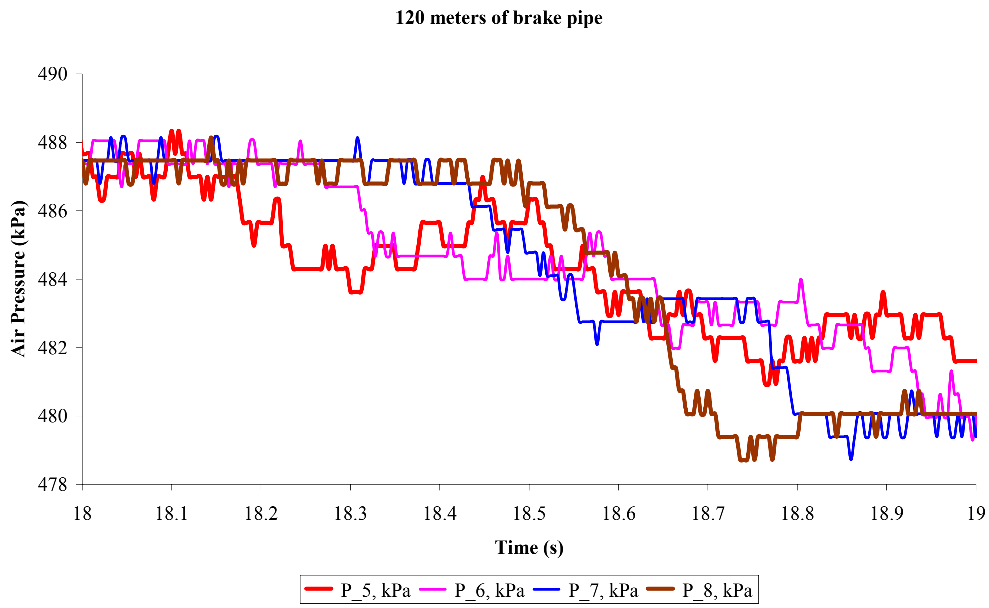

Figure 50: Gulp propagation with all 4 control valves operational.

4.1.5 Discussion

a) Rate of Reduction and Size of reduction from a single control valve operation

The minimum pressure reduction rate required to operate a control valve is 30 kPa/min (Westinghouse 1973). A reduction rate of ~ 100 kPa/min measured at the rear rake of 42 wagons has been shown for distributed power trains as shown in Figure 45. Further data from tests by Queensland Rail 04/12/2001 of longer trains have shown a reduction rate of 48 kPa/min at the rear of 92 wagons of a head end train, as shown in Figure 46. The pressure reduction rate of 54 kPa/min was chosen for the single control valve test to ensure that the valve would commence to operate. Previous testing with a pressure reduction rate of 30 kPa/min failed to operate the valve.

The results in Table 5 show that when a single control valve has been subjected to a brake pipe drop rate of 54 kPa/min, the valve has functioned as the pressure differential between the brake pipe pressure and the auxiliary pressure has approached 12 kPa. During the brake application, the start of the pressure wave in the brake pipe produced by the quick service volume of the control valve shows a sharp drop in brake pipe pressure of 3.4 kPa as measured at 13.94 seconds at transducer P5 shown in Figure 48. The pressure measured at 14.28 seconds at transducer P8 that is 120 meters from transducer P5, and shows the corresponding sharp drop of 3.3 kPa.

As shown in Figure 48 it takes 0.340 seconds for the pressure wave to travel from P5 to P8 a distance of 120 meters and with a velocity of 352 m/s. This compares well with the calculation of speed of sound in section 3.1.1 of 350.18 m/s of dry air and at 32^0 C with the variance from equation **(4.1)**.

b) Size of reduction from 4 control valve operation

The results from this test are shown in Table 6. Four control valves are operated in sequence by the propagation of the brake pipe pressure reduction, and local sharp pressure drops are developed by each quick service volume. The results have shown progressive increases in the local pressure reduction when four control valves are connected to the brake pipe.

The start of the pressure wave (a quick drop of 3.3 kPa) produced by the quick service volume of the first control valve was measured at 18.17 seconds at transducer P5 shown in Figure 50. The bottom of the pressure drop measured at 18.75 seconds at transducer P8 is a combination of the original pressure wave or gulp and the sum of the local reduction of pressure drop in the brake pipe produced by the quick service volumes of the control valves. The combined gulp has shown a drop in pressure of 8.2 kPa measured at the gulp at P8. The sum of the increase in the gulp had begun at P5 at 483.6 kPa and finished at P8 of 478.7 kPa and was an increase of 4.9 kPa in gulp in 120 meters with four control valves.

The tests as shown in Figure 50 show no increase in the combined local reduction in pressure after the 2nd control valve and it is this control valve that has a pipe bracket between the branch pipe and valve. The combined increase of the gulp pressure drop shown in this series of tests is seen after the 2nd control valve when the 3rd and 4th control valves have operated. Therefore the results of this test suggest that having an increasing number of control valves in a train line the pressure wave or gulp could be made to grow larger in size as propagation progresses. The gulp from the reduction ensuring feature and quick service volume is seen in Figure 46 where the gulp increases in size from wagon 55 to wagon 92.

4.2 Local Pressure reduction using different branch pipe sizes

4.2.1 Introduction

The objective of this experiment was to measure and compare the size of the gulp in the brake pipe due to the effects of different lengths and internal diameters of the branch pipe from the bulb action when a control valve operates.

Industry survey has shown that branch pipes connecting the control valve to the train brake pipe differ in both diameter and lengths see Figure 51. There are also two ways the branch pipe connects to the control valve. One system is to have the branch pipe connected to a port on the control valve. Another system uses a multi compartment reservoir which includes a mounting bracket. The control valve is mounted to this bracket and the branch pipe is connected to a port on this bracket. The mounting bracket is normally called a pipe bracket.

In these experiments the local pressure reductions developed when using different length and size branch pipes to a control valve pipe bracket were measured. The response of the system was recorded and analysed using pressure transducers and data acquisition.

Plastic branch pipe. Long steel branch pipe.

Figure 51: Branch pipes showing different material and lengths.

4.2.2 Equipment

For experimental measurements of the pressure reduction rate resulting from different length and size branch pipes, the pipe arrangement shown in Figure 39 was used. In this series of experiments, the 2nd control valve utilises a pipe bracket. A selected series of different branch pipes are connected between the tee at the brake pipe and pipe bracket. The transducers are fitted as shown in Figure 39 . From the data obtained after running the experiment, the rate of reduction and the size of the reduction can be established.

4.2.3 Method

Various branch pipes, of which two are shown in Figure 52, were connected between a tee in the brake pipe to the pipe bracket port. Each test was conducted with the air in the brake pipe being compressed to 500 kPa and allowed to stabilise. Air was then exhausted through an exhaust choke. The diameter of the exhaust choke used in these experiments was of 1.5 mm, this being to allow a comparison of the branch pipes with typical brake pipe train installations. These experiments were performed with all four valves connected to the brake pipe. The results were checked for consistency with three repeat tests. The pipe pressures were taken only from transducer P6 which is positioned after the 2nd control valve and as shown in Figure 39.

The test number along with the length and sizes of the branch pipe used are shown in Table 7.

Table 7: Branch pipe length and sizes.

Test No.	Branch pipe length (mm)	Branch pipe I.D. (mm)
608	150	20
700	800	20
718	800	12

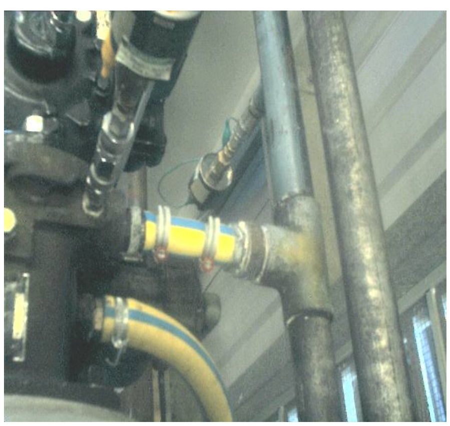

Figure 52: 20 mm x 150 mm and 20 mm x 800 mm branch pipes.

4.2.4 Results

The results shown in Table 8 and Figure 53 are from brake pipe pressures from 120 meters of pipe with 4 control valves at spacings as shown in Figure 38 and with the 2nd control valve having the pipe bracket.

These results of the local reduction in brake pipe pressure are extracted from three experiments of test numbers #608, #700 and #716 with the pipe pressure measurements from transducer P6 at the location shown in Figure 39.

Table 8: brake pipe pressures from different branch pipes.

Time (s)	Test #608 (kPa)	Test #700 (kPa)	Test #718 (kPa)	Comments
0.412	488.4	488.4	488.4	All start to drop in pressure
0.436	487.1	486.4	487.1	#718 drops least
0.468	484.4	484.4	485.1	#700 drops below others
0.492	485.1	484.4	485.1	#700 bottom of trough
0.556	485.1	483.7	485.8	#718 starting to climb

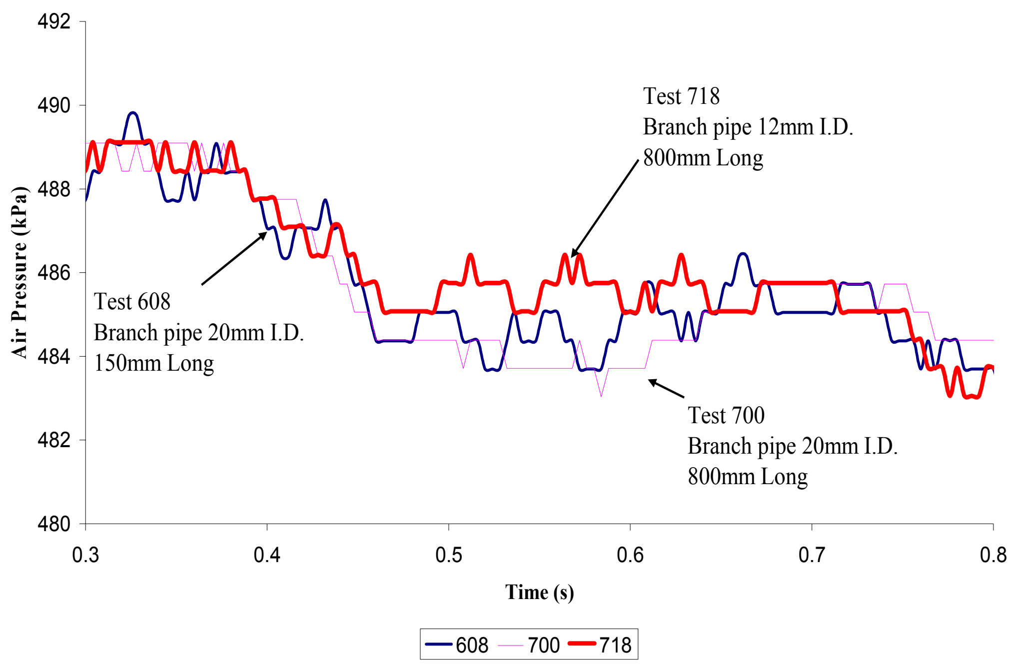

Figure 53: Gulps in the brake pipe with different size and length branch pipes.

4.2.5 Discussion

The results from Figure 53 show a difference between the greatest local pressure reduction reached in test #718 and test #700 was 1.3 kPa with #700 giving the lowest pressure at 483.7 kPa. Although measurable, this difference is almost too small to be significant when the measurement resolution is 0.67 kPa. The results show that the time that each local pressure reduction remains at the lowest pressure is also different for each sized branch pipe.

The time the pressure of test #608 remains at its lowest local pressure reduction of 484.8 kPa is 0.132 seconds. The time on test #700 is 0.076 seconds and the time on test #718 is 0.204 seconds. The results show that for test #608 the bulb function takes 0.072 seconds to induce the local pressure reduction of 4 kPa. The time for the brake pipe pressure in test #700 to reach its lowest point is 0.144 seconds with a local pressure reduction of 4.7 kPa. In test #718 the time taken to reach the lowest point is 0.076 seconds with a local pressure reduction of 3.3 kPa.

Results have shown that by using a 20 mm I.D. branch pipe 150 mm long and when compared to a branch pipe of the same diameter and 800 mm long, the local reduction in pressure drop reached can be the same. As $h_L \alpha L$ it can only be concluded that the difference is too small to measure with the equipment used. When the branch pipe is 12 mm I.D., both the reduced pressure in the brake pipe and the time the pressure is at the reduced level is less than for the larger diameter branch pipes as expected, (Darcy-Weisbach equation shows that $h_L \alpha \frac{1}{d^5}$). The three different branch pipes used in these tests have shown that the cross sectional area of the branch pipe has the major effect on the size and duration of the local pressure reduction in the brake pipe.

4.3 The Quick Service Volume

4.3.1 Introduction

The purpose of experiments with the quick service volume or 'bulb' was to compare the size of the gulp in the brake pipe from the two volumes that are used by the Australian rail industry. Another objective in this experiment was to observe the action of the bulb and the gulp in the brake pipe while performing a series of brake pipe reductions.

The quick service volume is a small reservoir built within the basic control valve body. Its purpose is to assist in the application propagation and therefore bring about a more instantaneous application of brakes throughout the train. Its capacity is designed to correspond to the volume of brake pipe on each vehicle and therefore there is a necessity for differing capacities for different wagon lengths. There are two capacities used with the current Australian control valve as explained in 2.4.3, namely 33 $x10^{-5}$ m^3 and 59 $x10^{-5}$ m^3. The train brake pipe lengths to which the aforementioned sizes are applied are up to 23 meters and from 21 to 37 meters respectively (Westinghouse 1989). The results from this series of tests will show the difference in size of the local reduction in the brake pipe for these two quick service volume sizes. The responses from bulb operations in the brake pipe of successive applications are also investigated in this series of tests.

4.3.2 Equipment

For experimental measurements of the local pressure reduction rate resulting from different size quick service volumes, the brake pipe rack and control valves as shown in Figure 39 was used. In this series of experiments, the 1st control valve is tested with the different quick service volume or bulbs. The tests also included the use of a volume connected directly to the brake pipe with the size of a large bulb. The transducers are fitted as shown in Figure 39. The container was connected to the brake pipe with a ball valve as shown in Figure 61.

4.3.3 Method

The different quick service volumes tested were of 33 $x10^{-5}$ m^3 and 59 $x10^{-5}$ m^3. These are referred to as medium and large bulbs (Westinghouse 1989).

Data was extracted from each file to produce a comparison graph showing the local pressure reduction in the brake pipe after the control valve. The 'local gulp' of air pressure was also measured at the control valve. Each test was conducted with the air in the brake pipe being compressed to 500 kPa and allowed to stabilise. Air was then exhausted through an exhaust choke. Testing that included a series of applications of the brakes from 500 kPa without making a release application was also included.

4.3.4 Results

The results shown in Figure 54 are from brake pipe pressures from 120 meters of pipe with a transducer connected to the brake pipe after the first control valve. These results of the local reduction in brake pipe pressure are extracted from two experiments of test numbers #073 and #074 with the pipe pressures from transducer P5 in each test with the location shown in Figure 39.

Table 9 is produced from the data in Figure 55.

Table 9: The local reduction in brake pipe pressures.

Time (s)	$MLPR_{(1)}$ (kPa)	$LLPR_{(2)}$ (kPa)	Comments
8.684	487.4	487.4	Pressures aligned with time
8.728	484.7	485.4	Start of corresponding gulp of the medium bulb
8.732	482.1	483.4	Start of corresponding gulp of the medium bulb
8.74	485.4	484.7	Bottom of corresponding gulp large bulb
8.748	484.1	485.4	Bottom of corresponding gulp large bulb
8.768	482.1	483.4	Bottom of local pressure reduction medium bulb
8.776	482.1	482.7	Bottom of local pressure reduction large bulb

Explanatory notes for the above table

(1) MLPR medium bulb local pressure reduction
(2) LLPR large bulb local pressure reduction

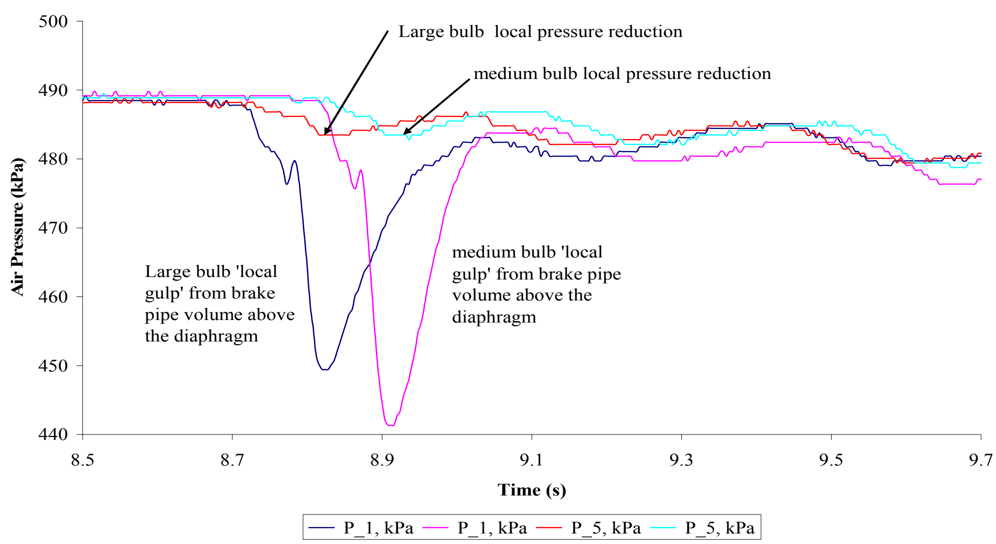

Figure 54: The 'local gulp' from a medium and a large bulb.

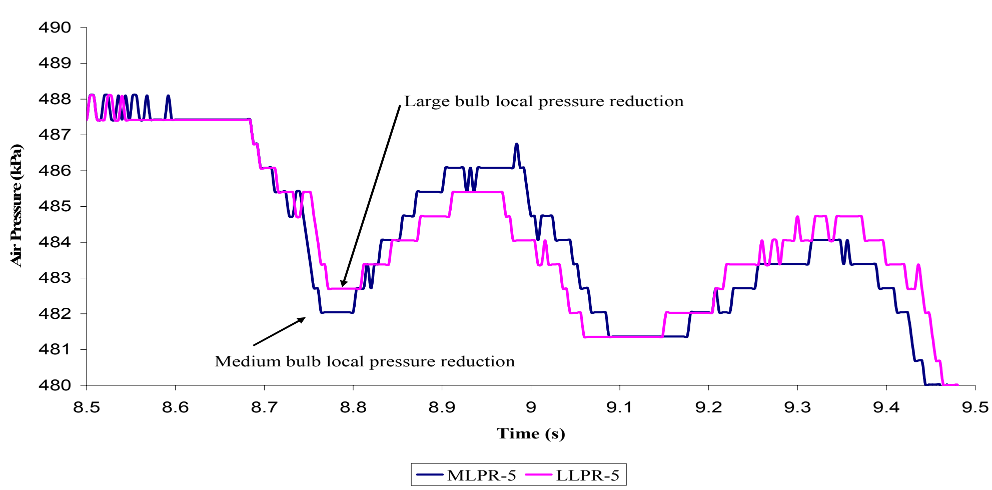

Figure 55: Gulps produced by a medium bulb and large bulb.

The results shown in Figure 56 are from transducers at the bulb and positioned after the control valve. The test shown in Figure 56 included successive brake applications without the brakes being released between the applications. These results show the bulb being filled at the first brake application and then leaking down before the next application.

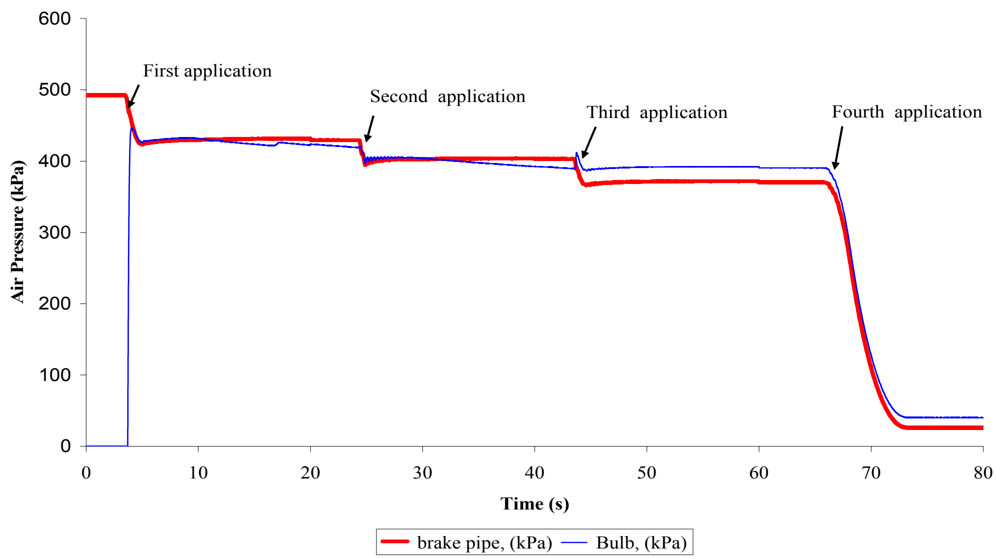

Figure 56 : Bulb pressures after four brake applications.

4.3.5 Discussion

The pressure measurements were taken from the location at transducers P1 and P5 as shown in Figure 39 of each test. The results in Figure 54 show the comparison of 'local gulp' reached between the medium bulb and the large bulb. The results also show a slight gulp within the larger 'local gulp' pressure line as the brake pipe pressure above the diaphragm is dropping as the bulb is being filled. This slight gulp corresponds to the instant when the control valve disconnects the bulb to the brake cylinder at the end of the inshot function. The local pressure reduction seen in the brake pipe as shown in Figure 55 corresponds to the larger 'local gulp' seen at the control valve and shown in Figure 54.

This experiment has shown a difference of 0.6 kPa between the local pressure reductions in the brake pipe after a control valve operation. This difference is the same as the bit resolution of 0.67 kPa of the data so the significance of the difference is debatable. The times that each gulp stays at the lowest pressure are also the same at 0.032 seconds.

The gulp or local reductions of pressure in the brake pipe as seen by these tests are between 5.3 kPa and 4.7 kPa. These reductions taken alone are not enough to produce a trigger effect on the next control valve as the valve needs a differential between the Auxiliary reservoir pressure and the brake pipe pressure of at least 10 kPa to 12 kPa. There is seen from the tests conducted of the different bulb sizes that little difference in the local pressure reduction has been achieved using the larger bulb. The use of multiple control valves may increase this little difference in the local reduction of the brake pipe pressure. The results shown in Figure 50 showing increases in the gulp size can give the impression that with further lengths of pipe and more control valves, the sum of the gulp or local pressure reduction from each valve would finally reach a stage to be large enough to trigger a control valve.

An observation from the multiple application tests performed, (when closing of the brake pipe exhaust after the control valve had operated and then opening the exhaust again) was that there was no second gulp function in the brake pipe shown in Figure 56. The pressurised quick service volume will stay pressurised until an increase occurs in brake pipe pressure. The control valve then releases the pressurised volume to atmosphere this is when the brakes are being released as explained in 2.4.1. The results from the repeat application tests show the bulb leaking down in pressure, but to below the brake pipe pressure between applications and this shows a faulty control valve. The bulb should follow the brake pipe pressure. At the third application the bulb pressure raised as the pressure from the brake pipe was connected but stabilised at 390 kPa which was surprising. Again because of the faulty control valve the bulb pressure should have followed the brake pipe pressure down to 370 kPa. Although at this time the application showed a small gulp in the brake pipe of ~ 4 kPa as the bulb was filled. The brake pipe pressure was 13 kPa above the bulb pressure, at the start of the third brake pipe reduction and would explain the small gulp seen in the brake pipe.

4.4 The Pipe Bracket and Isolation Cock

4.4.1 Introduction

The purpose of the pipe bracket and isolating cock experiments was to compare the size of the gulp in the brake pipe under two conditions, which are (1) when a pipe bracket is used and (2) when a pipe bracket is not used. A second objective of these experiments was to compare the size of the gulp in the brake pipe when different sized passageways are used in the isolating cock.

The pipe bracket used in these experiments is mounted between the control valve and the multi-compartment reservoir. Mounted to the pipe bracket and connected by internal air passages is the isolation cock. Air from the brake pipe via the branch pipe is routed with passageways through the pipe bracket into the isolation cock and then back into the pipe bracket where it is connected to the control valve. The air also flows through a filter attached to the isolation cock.

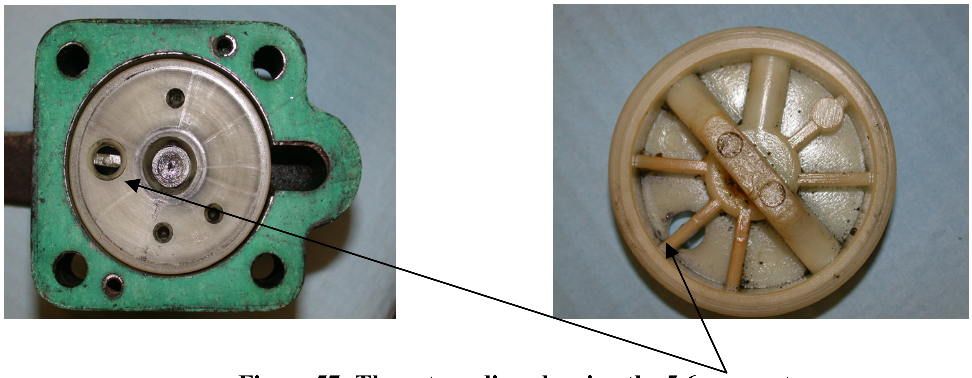

Figure 57: The rotary disc, showing the 5.6mm port.

These experiments are to investigate and compare the size of the local reduction pressure wave created in the brake pipe from the action of the bulb when using different sizes of the port in the rotary disc of the isolation cock. The comparison between using a pipe bracket and having the branch pipe connected directly to the control valve is assessed separately. The experiments in investigating the actions of the local pressure reduction in a brake pipe from (1) a pipe bracket with an isolation cock and (2) a control valve without a pipe bracket were completed as two separate sets of experiments.

4.4.2 Equipment

In the first series of experiments, the 2nd control valve within the brake pipe rack utilises a pipe bracket used in conjunction with a combined reservoir. The isolation cock that is connected to the pipe bracket is tested with two different port sizes. The pipe bracket was examined and found to have approximately 132 mm of passageways of which range in diameters from 11 mm to 8.7 mm. The brake pipe air was connected to the control valve via the pipe bracket. The combined isolation cock and filter utilises a rotary disc as a valve and has a filter of the paper element type of 25 micron attached. The passageways in the isolation cock have a combined length of approximately 150 mm and diameters range from 11 mm to 9.5 mm. The standard diameter of the port in the rotary disc is 7.65 mm with a bridge of 2 mm wide across it and therefore has an effective diameter of 5.6 mm and an area of 2.463×10^{-5} m^2.

Tests are also completed with a modified rotary disc. The size of the port in the modified rotary disc was 9.5mm with an area of 7.088×10^{-5} m^2 with the bridge removed. The 9.5 mm diameter matched the size of the immediate passageways either side of the rotary disc. The two diameters of the branch pipe that were used were 20 mm and 12 mm and were both of the same length. The inlet diameter of the control valve will not allow a larger diameter than 20 mm. For the second series of experiments a branch pipe of 20 mm and 800 mm in length is connected to a pipe bracket and a branch pipe with the same internal diameter and length is connected to a control valve which does not utilise a pipe bracket. The diameter of the exhaust choke used in these experiments was of 1.5 mm.

4.4.3 Method

Each test was conducted with the air in the brake pipe being compressed to 500 kPa and allowed to stabilise. Air was then exhausted through an exhaust choke.

4.4.4 Results

The results of the local reduction in brake pipe pressure created by different branch pipe diameters and rotary port diameters are presented from four experiments of test numbers 700, 705, 711 and 716. The branch pipe diameters and port sizes are shown in Table 10. The response of brake pipe pressure from transducer P6, which is located after the branch tee for the branch pipe connection to the pipe bracket, is shown in Figure 58.

Table 10: Branch sizes and port sizes.

Test No.	Branch pipe length (mm)	Branch pipe I.D. (mm)	Rotary disc port size (mm)
700	800	20	7.65
705	800	20	9.5
711	800	12	9.5
716	800	12	7.65

Table 11 is produced from the data in Figure 58 the transducer P6 is at the locations in Figure 39

Table 11: Pressures and times at transducer P6.

	P6 (kPa)	P6 (kPa)	P6 (kPa)	P6 (kPa)	
Time (s)	#700	#705	#711	#716	Comments
0.072	487.5	487.5	487.5	487.5	Pressures aligned with time
0.112	485.5	485.5	485.4	486.1	Small pipe shows less drop
0.152	483.4	484.1	483.4	484.1	Bottom of trough of 716
0.180	483.4	483.4	484.7	484.7	716 rising
.0.220	482.8	483.4	484.1	485.4	700 at bottom of trough
0.292	482.8	483.4	484.1	486.8	700 starting to rise
0.368	484.7	484.7	484.7	486.8	All at top of local gulp

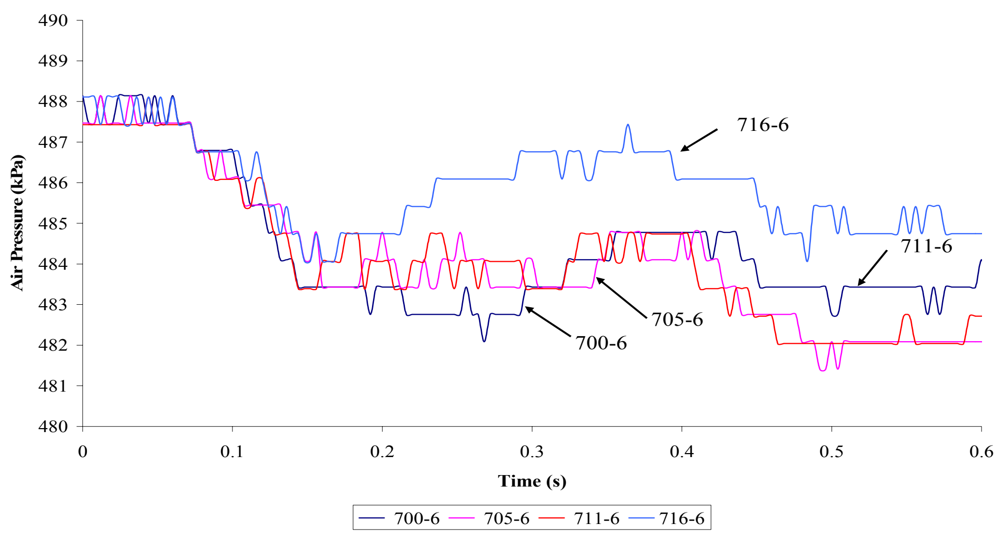

Figure 58: Gulps with different branch pipes and port diameters.

The results of the local reduction in the brake pipe pressure from a control valve connected to a pipe bracket and of a control valve without a pipe bracket are shown in Figure 59. The branch pipe for all four tests were of 20 mm I.D. and with a length of 800 mm, and are as shown in Table 12

Table 12: Test numbers with various pipe brackets.

Test No.	Transducer	Branch pipe length (mm)	Branch pipe I.D. (mm)	Comments
91	P3	800	20	No pipe bracket
91	P7	800	20	No pipe bracket
72	P2	800	20	Pipe bracket
72	P6	800	20	Pipe bracket

The results shown in Figure 59 and Table 13 are at the transducer locations as shown in Figure 39.

Table 13: Pressures from control valves with and without a pipe bracket.

	P3 (kPa)	P7 (kPa)	P2 (kPa)	P6 (kPa)	
Time (s)	# 91	# 91	# 72	# 72	Comments
8.732	486.1	486.8	486.1	486.8	Pressures aligned with time
8.788	484.8	486.8	484.8	486.8	Drop in pressure at above diaphragm
8.848	473.3	485.5	461.2	484.1	P7-91 shows corresponding 'small gulp'
8.88	448.4	483.4	420.8	482.1	P6-72 at lowest pressure
8.89	447.1	482.1	412.1	482.1	P7-91 still falling
8.988	459.2	480.1	433.6	482.7	P7-91 at lowest pressure P6-72 rising

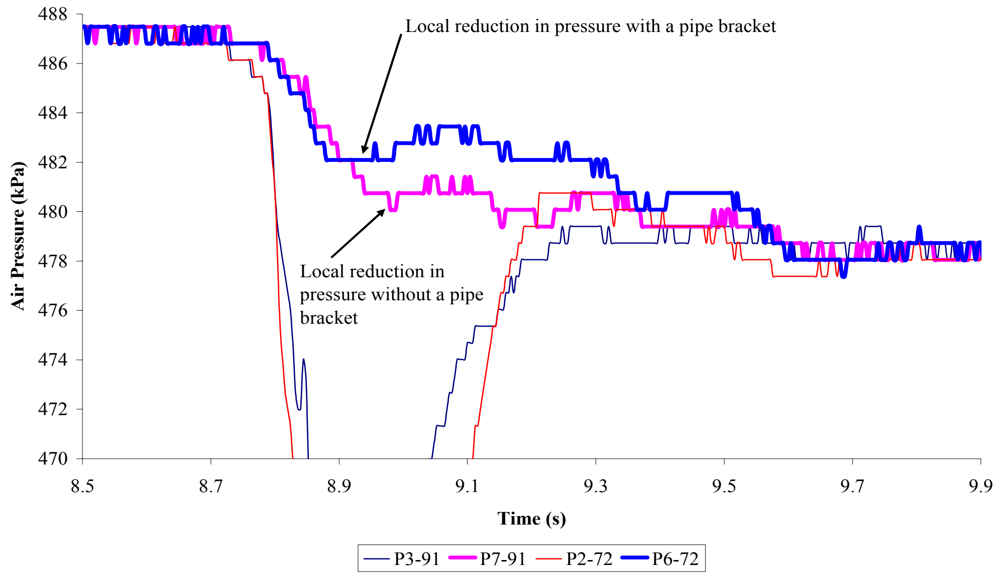

Figure 59: Gulps in the brake pipe with and without a pipe bracket

4.4.5 Discussion

The first series of experiments the brake pipe pressures were taken only from the transducer P6 which is positioned after the 2nd control valve as shown in Figure 39. The results from Figure 58 show a difference of the lowest local pressure reduction reached between test #716 and test #700 of 1.6 kPa with #700 being the lower at 482.8 kPa. The results show that the time that each local pressure reduction stays at the lowest pressure is different for each rotary port and branch pipe diameter. The time the pressure of #700 stays at its lowest local pressure reduction of 482.8 kPa is 0.076 seconds and could best be described as a 'hold time'. The 'hold time' on test #705 is 0.172 seconds. Test #711 shows a 'hold time' at its lowest point is 0.172 seconds. The time period that the pressure of #716 stays at its lowest local pressure reduction of 484.3 kPa is 0.02 seconds.

The results show that for test #700 and test #711 it takes 0.072 seconds to reach the lowest local pressure reduction of 4 kPa and this could be called a 'drop time'. The 'drop time' for test #705 to reach its lowest point is 0.092 seconds with a local pressure reduction of 4 kPa. In test #716 the 'drop time' taken to reach the lowest point is 0.08 seconds with a local pressure reduction of 3.3 kPa.

These results show that when a branch pipe is a smaller diameter, the enlarged port in the rotary valve has little effect on the local pressure reduction in the brake pipe.

These observations are of the pressure response of tests #705 and test #711 which show a similar response to each other.

The results from test #716 show that with a small diameter branch pipe and a standard port size in the rotary disc, the size of the local pressure reduction is the least in both pressure reduction and the time period which the lowest pressure is maintained. The results of test # 700 can be compared to a previous experiment seen in section 4.2 and Figure 53 of the local pressure reduction using different branch pipe sizes. In that section, test #608 was setup with a branch pipe of 20 mm I.D. and 150 mm long. This test # 608 showed a reduction of 4 kPa as seen in Table 8 and the branch pipe was connected via the pipe bracket with a standard rotary port. This compares well with the 'hold times' and 'drop times' with test #700 of which is using the same size diameter branch pipe but 800 mm long. The results from the tests completed in this series indicate that the smaller internal size of a branch pipe as shown with test #716 will give the smallest local pressure reduction, occurring in the least amount of time after a control valve operation. The enlarging of the rotary port size as shown with test #711 can increase the time that the local reduction pressure drop will stay at its lower pressure when the branch pipe internal diameter is smaller.

The second series of experiments give the result that a pipe bracket can have an influence on the size of the local pressure reduction drop in the brake pipe. The results from Figure 59 and shown in Table 13 show a difference of 2 kPa between the two lowest pressures obtained in these tests of the local reduction in brake pipe pressure or gulp. The local pressure drop in the brake pipe that has been shown is 6.7 kPa for a control valve without a pipe bracket. When a pipe bracket is used the local pressure drop is shown as 4.7 kPa. These pressures were obtained using a single control valve in separate tests.

4.5 Bulb filling times

4.5.1 Introduction

An evaluation of the effect of the restrictive passageways of the pipe bracket and control valve is the first objective of this group of experiments. The purpose of the second part of these experiments is to measure bulb filling times and to compare the time that was taken to fill two different sized bulbs with and without the restrictive passageways of the pipe bracket.

The quick service volume or bulb of a control valve is filled from the compressed air in the brake pipe at the beginning of a brake application. Between the bulb and the branch pipe are passageways of approximately 730 mm in length. The diameters of these passageways vary between 5.6 mm and 11.5 mm. The first of these tests is to compare the difference in brake pipe pressure response when a gulp is provided with and without these restrictive passageways.

A ‘container’ or ‘experimental dummy bulb’ as shown in Figure 61 with the same volume as a large bulb ($59 \times 10^{-5}\ m^3$) was connected directly to the brake pipe to give a comparison of the bulb volume operation without the restrictive passageways. The second experiment a tube with a small diameter is connected between the 'container' and brake pipe. The length in the pipe is adjusted to give the same response in the brake pipe as would occur when a standard large bulb is connected via the pipe bracket and control valve.

The two different sizes of bulbs that are used in most present day Australian railway industry would be assumed to have different filling times and the passageways within the pipe bracket as seen from previous testing of the Quick service volume may have an influence on these times. These tests are to establish the time it takes to fill a quick service volume or bulb to its maximum pressure with two different configurations of branch pipe connections, where one connection of the branch pipe eliminates the pipe bracket.

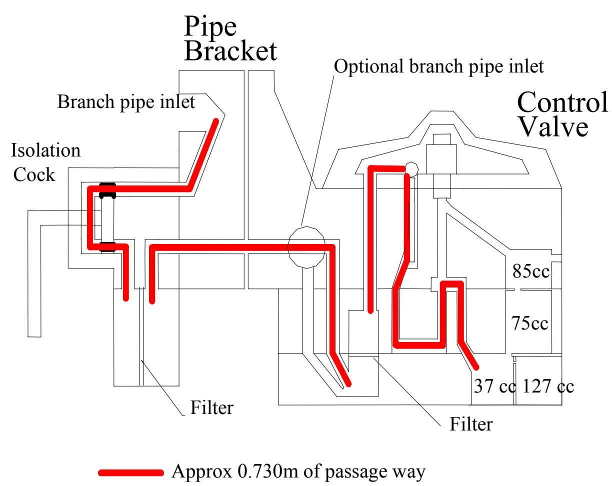

Figure 60: Passageways in the pipe bracket and control valve of 730 mm.

4.5.2 Equipment

The equipment used in the first of the tests was the brake pipe with transducers at the locations as shown in Figure 39. The 'experimental dummy bulb' or 'container' used was made to the size of a large bulb of a control valve and had a volume of 59 x 10^{-5} m^3. The length and diameter of the long length tube had been previously determined through experimental results comparing the ‘local gulp’ from valves with and without the pipe bracket and is of 2.1 m in length and 6 mm in diameter.

Figure 61: The ‘container’ connected to the brake pipe.

The second of these tests used two different control valves one having a medium bulb of 33 x 10^{-5} m^3, the other having a large bulb of 59 x 10^{-5} m^3. The branch pipe used was 20 mm I.D. and 800 mm in length.

4.5.3 Method

These tests are broken into two parts. For the first part of the tests, an ‘experimental dummy bulb’ or ‘container’ was connected to the brake pipe with a ball valve as shown in Figure 61. The brake pipe pressure, when at its stabilised pressure of 500 kPa was opened to atmosphere by a valve through an exhaust choke, as in a brake pipe application at a rate of ~ 270 kPa/min. Then after approximately 7 seconds the ball valve that connected the ‘container’ to the brake pipe was opened, the ‘experimental dummy bulb’ would then be pressurised and the brake pipe pressure would drop accordingly. This type of operation produces a gulp or local reduction of pressure in the brake pipe as would a control valve bulb operation.

The second part of these tests used the 2nd control valve in the brake pipe setup as shown in Figure 39. The branch pipe used was either connected to the pipe bracket or to the optional port on the control valve for comparison purposes of the fill times.

4.5.4 Results

For the first experiment, the 'container' was connected directly to the brake pipe and the results show a gulp or local reduction in the brake pipe of 11.5 kPa drop in pressure. The second part of the tests, the 'container' was then connected to the brake pipe with a long length tube. The results show a reduction or gulp in the brake pipe when the 'container' was filled was at a 5.4 kPa drop, both of these local pressure reductions or gulps are shown in Figure 62.

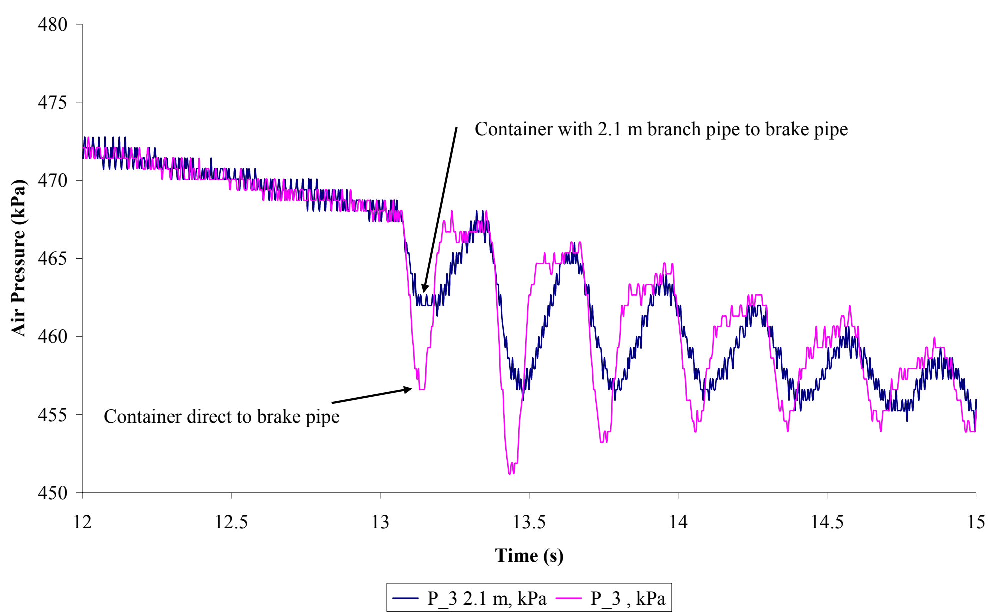

Figure 62: Comparison of bulb having long and short branch pipes.

The results from the 2nd part of these tests are shown in Figure 63, and show a decrease in the filling times of a medium and large bulb. The decrease shown is between 24.5% and 53% respectively. The decrease was achieved by changing the branch pipe connection from the inlet port on the pipe bracket to the alternative inlet port on the control valve. The filling times of the bulbs are shown in Table 14 and made from Figure 63.

Table 14:Times when medium and large bulbs have filled.

Test No.	Time when bulb has filled to maximum pressure (s)	Comments
620	0.208	Medium bulb, branch pipe direct to control valve
618	0.276	Medium bulb, branch pipe to pipe bracket
605	0.280	Large bulb, branch pipe direct to control valve
601	0.596	Large bulb, branch pipe to pipe bracket

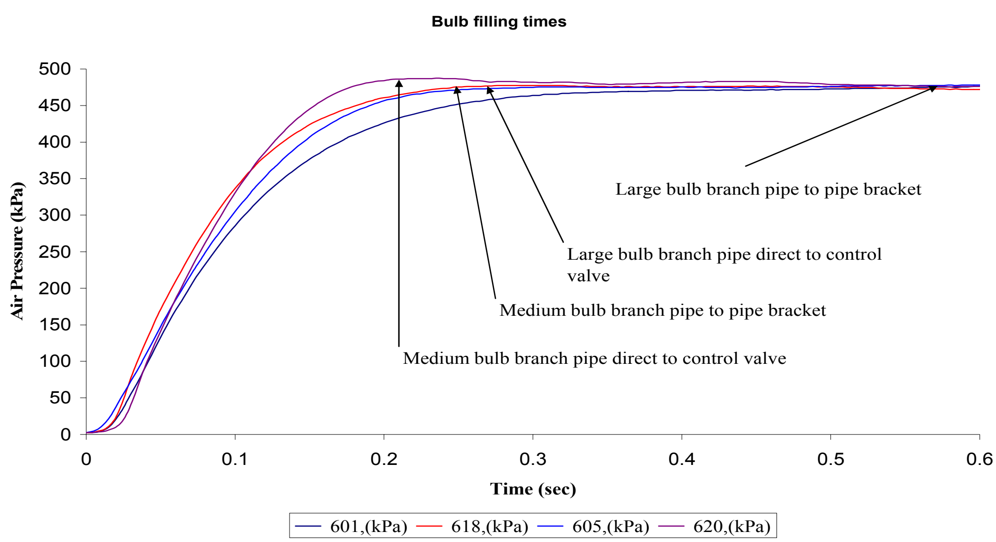

Figure 63: Bulb filling times for medium and large bulbs.

4.5.5 Discussion

The tests using an 'experimental dummy bulb' showed that the pipe bracket and control valve passageways have an effect on the local reduction pressure in the brake pipe. The crude, but directly connected volume as seen in Figure 61 gave an increase in pressure reduction or gulp of 6.1 kPa. The local pressure drop seen in the brake pipe when the container is connected to the brake pipe was 11.5 kPa. When the 'container' is used with a long length tube the local pressure drop seen in the brake pipe is reduced to 5.4 kPa. This pressure drop of 5.4 kPa is similar to the pressure drop seen in the previous tests in section 4.4 and Figure 59 when using a pipe bracket connected to a 20 mm diameter and 800 mm in length branch pipe using a large bulb taking into account the resolution of 0.67 kPa.

The second part of these tests has shown that the passageways in the pipe bracket have an effect in the filling of the bulb. The tests show that a large bulb with a pipe bracket takes the longest time to fill to its maximum pressure, as shown in Figure 63 and Table 14. The tests also show that when the pipe bracket is not used as a connection for the branch pipe, the time to fill a large bulb is decreased by 53%.

From the tests preformed, it can be seen that the pipe bracket and control valve that restrictions that can be grouped into individual classes. All the passageway restrictions in the pipe bracket could be classed overall as an orifice or a choke for that part of the control valve assembly. The restrictions of the passageways in the control valve that lead to the bulb could also be classed overall as an orifice or choke. For the purposes of discussions these 'orifice' or 'choke' will be called 'combined orifice'

By analysing the graphs in this section can give an indication of what variation on the size of the local pressure reduction seen in the brake pipe is made by each 'combined orifice'.

From the examples seen,

- When a control valve with a pipe bracket has shown a local reduction 4.7 kPa. It is noted that there are two 'combined orifice' between the bulb and the brake pipe.

- When the control valve is used without the pipe bracket the local reduction is at 6.7 kPa. Only one ‘combined orifice’ is between the bulb and the brake pipe.
- When the ‘experimental dummy bulb’ is connected to the brake pipe the local reduction in the brake pipe is seen as 11.5 kPa. There is no ‘combined orifice’ between the bulb and the brake pipe.(Although small restrictions will exist in pipe fittings)

Pressure drop variation due to different restrictions in the flow path:

- Pipe bracket and control valve……..4.7 kPa
- Control valve……………………….6.7 kPa
- ‘experimental dummy bulb’ ……….11.5 kPa

Against the 11.5 kPa value of the ‘experimental dummy bulb’ the above values indicate that the ‘combined orifice’ effect of the pipe bracket is of a value of 4.8 kPa. The value the ‘combined orifice’ effect of a pipe bracket and a control valve is at 6.8 kPa.

It must be noted that the start of local reduction in the brake pipe of the ‘experimental dummy bulb’ was when the brake pipe pressure was at a value of approximately 468 kPa. It would have been expected that if the brake pipe pressure was at the normally higher value of 10-12 kPa below the nominal 500 kPa when a control valve operates, then the local pressure reduction of the ‘experimental dummy bulb’ would be more than 11.5 kPa due to greater branch pipe flow.

If this could be the case, then the value of the ‘combined orifice’ effect of a pipe bracket and a control valve may be greater than 6.8 kPa.

5. General Discussion

The first of the tests using the four control valve test rig showed that the magnitude and duration of the pressure drop (in the brake pipe) associated with the gulp increases as more control valves in a brake line are triggered. The pressure gulps in the experimental rig propagated with a speed equal to sonic velocity. Note also that the experimental setup included one control valve with a pipe bracket, the other three valves were not fitted with pipe brackets. Testing showed that valves without pipe brackets induced larger gulps. The increase in the gulp is interesting, as the pipe lengths on the test rig were matched to the bulb volumes used with spacings of 37 m, 37 m and 43 m

Figure 38. The speed of propagation observed, over four control valves is faster (352 m/s) than was expected as the pipe lengths of the VSAL/S type wagons (39.06m) are above the upper extreme of the recommended operational range for a long bulb (23-37 m). Results from a QR train test, Figure 46, do not show this type of propagation speed up to wagon #52 (161 m/s). The possible reasons for this anomaly will be discussed along with other issues with pressure profiles in page 94.

The testing of medium (33 $x10^{-5}$ m^3) and large (59 $x10^{-5}$ m^3) bulbs using a pipe bracket for the branch pipe connection, did not show any measurable differences in the size of the gulp in the brake pipe on the experimental rig. It was also noted there has been no information from industry or valve manufactures in the literature review as to what size gulp would be obtained from bulbs to the equivalent pipe lengths they were assigned to. Manufactures only provide recommendations for pipe length for the two different bulb sizes (Westinghouse 1989).

Results from a 'experimental dummy bulb' of 59 x10^{-5} m^3 (manufactured from pipe fittings) that was directly connected to a brake pipe without the restrictive passageways of the pipe bracket and control valve gave large brake pipe gulps (~11.5 kPa). The only difference between this bulb and the standard large bulb is the restrictions provided by different size, lengths and sharp angles of the many small passageways within the pipe bracket and control valve.

The approximated restrictions were tested from comparing valve response by using the 'experimental dummy bulb' or 'container'. A long tube from the 'container' to the brake pipe was used to represent the restrictions of a pipe bracket and control valve. The result of this comparison by using the long tube showed that the restrictions equated to a branch pipe of 2.1 m long and with a diameter of 6 mm. In a previous test it is noted that in Figure 59 section 4.4 in a comparison where a pipe bracket is used and also bypassed when using a large bulb, gave results of the gulp size at 4.7 kPa with a pipe bracket Figure 64 and 6.7 kPa without the bracket Figure 65, these results again showed the effects of restrictions of a pipe bracket. These effects of the restrictions of the pipe bracket are also seen in the bulb filling times of a large bulb when the branch pipe was used to bypass the pipe bracket as shown in the results from section 4.5 and Figure 63 when the times for filling a large bulb was at 0.280 seconds when bypassing the pipe bracket and 0.596 seconds when using a pipe bracket.

The possible benefits of the large bulb therefore appear to be lost due to the restrictions in the pipe bracket passageways. The possibility is thus raised that the resizing of bulbs to the large volume of brake pipe for VSAS/L wagon pairs was ineffective in increasing the gulp size. This argument is given more weight when it is realised that the large bulb development was only supported experimentally by the Westinghouse testing facility which was not equipped with pipe brackets with combined reservoir and relay systems. Overall results from all tests show that the pipe bracket or more exactly the passageways within the pipe bracket restrict the size and duration of the gulp in the brake pipe local pressure.

The pipe bracket restrictions Figure 64 also appear to nullify effects of different branch pipe lengths. It was noted that when the branch pipe has shorter or longer lengths in the range of 150 mm and 800 mm and having the same internal diameter there is no measurable difference seen in the size of the gulp when tested with a connection between the brake pipe and pipe bracket as in section 4.2, Figure 53. Conversely, gulp behaviour was observed to change when the branch pipe was connected to the control valve directly as in section 4.4, Figure 59.

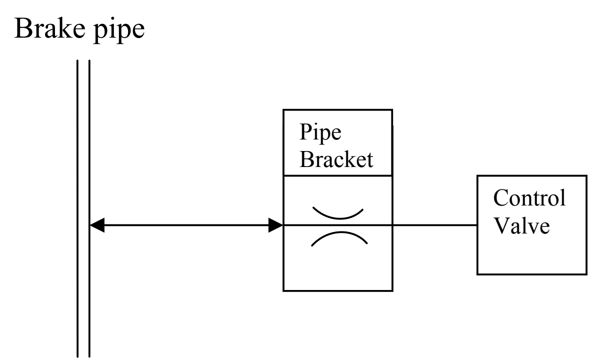

Figure 64: Branch to pipe bracket.

The tests of different branch pipe dimensions also showed that when the branch pipe was connected directly to the control valve, the bulb filling times were reduced as shown in Figure 63, section 4.5.

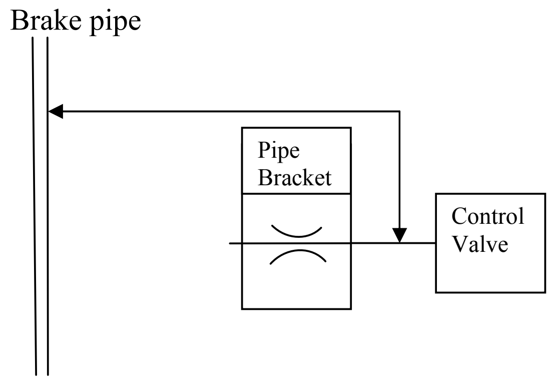

Figure 65: Branch pipe to control valve.

In the tests conducted two sizes of branch pipe used and were at 20 mm and 12 mm internal diameter. The branch pipe when connected to the pipe bracket has shown that the gulp was basically unmodified with different lengths of a branch pipe of 20 mm internal diameter, but when the branch pipe was changed to 12 mm internal diameter the gulp changed. At this point the restriction in the branch pipe became as significant to the gulp as the restrictions in the pipe bracket passageways.

Testing has confirmed that no benefit from the quick service volumes can be expected in the next successive brake applications. The design of the Australian brake system is such that the bulb pressure is held until the brakes are released (2.4.1).

A further issue to be considered is that the reduction ensuring valve only gives an initial charge of bulb air to the brake cylinder or dummy. It is to be noted that a change to the Australian control valve (WF5) now has the reduction ensuring valve being pilot operated by the bulb pressure (Westinghouse 2001). In this type of operation the brake pipe air above the diaphragm is connected to the dummy brake cylinder volume via the pilot operated reduction ensuring valve instead of using the bulb volume to a pressure of 70 kPa. The reduction ensuring valve of the WF5 valve, as with earlier valves when using relayed type equipment will connect to a fixed volume, which is the dummy brake cylinder and therefore adds a fixed volume to the bulb and therefore size of the gulp in the brake pipe by the bulb action. When the control valves are used with non-relayed equipment the reduction ensuring valve will be connected directly to the brake cylinders. It is noted that the volume of the cylinders can change to a larger volume than the fixed dummy cylinder volume, due to the number of cylinders and the stroke of the cylinders (if adjustment is not maintained). The gulp in the brake pipe will then change due to the larger volumes of the cylinders.

The interesting results from tests of quick service volume (see section 4.3.4), with a leaking bulb has demonstrated the possible benefits of venting bulbs. The effects of the leaking bulb has shown results that could be seen as similar to the American control valves in sections 2.3.2 and 2.3.3, where the Accelerated Application Valve (AAV) and the preliminary Quick Service Valve (Q.S.1) each vent a small part of the brake pipe air to atmosphere as a measure to increase the pressure reduction propagation rate. The AAV of the American system will vent a small portion of brake pipe air also on the next lower brake pipe reduction and therefore help to increase the pressure reduction propagation rate for the next brake application.

The construction of the bulb in the Australian valve as mentioned, if vented before a brake release is made, would cause the diaphragm to move to the release position and apply the brakes. It remains that the separate use of an Accelerated Application Valve or similar style valve may improve the lost propagation performance of successive applications on Australian systems.

The remaining discussion attempts to relate these experimental results to the brake pipe operation in long pipes. The exhaust of a brake pipe at a head end locomotive to give a reduction of pressure would make a pressure profile along the train as shown below in Figure 66. Superimposed on the profile will be the gulps as they are generated. Based in the experimental and industry data four different regions of operation can be suggested.

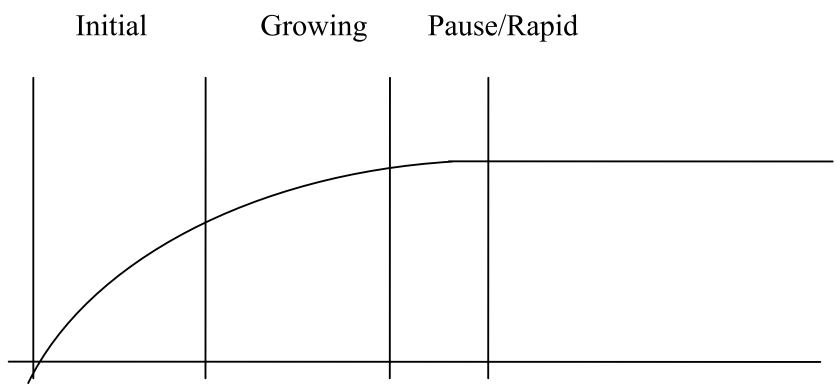

Figure 66: Brake pressure profile along the train.

1. In the initial section as the pressure is falling at the beginning of a long rake. The behaviour is dominated by the brake pipe exhaust. The first of the control valves are triggered by the high brake pipe pressure reduction rate and the high differential between the brake pipe and auxiliary reservoir pressures. The bulb action in this region is difficult to observe experimentally as air is exhausting rapidly via the exhaust in the locomotive. This was also demonstrated on the test rig with large exhaust chokes. With results from the QR graph (Figure 46) the propagation rate up to wagon #28 of a long rake where one valve operates over 39.06 meters of brake pipe has shown to be 123 m/s but begins to increase as the pressure profile tends to flatten, wagon # 52 shows a rate of 161 m/s.

2. A second issue is that a very long train stores a large volume of air in the pipe. With larger pipe volumes, bulbs will be less effective at dropping pressure. This effect is nullified at the front of the train via the rapid exhaust at the locomotive. So, as the pressure reductions due to pipe exhaust, at a given time can be smaller when located further from the locomotive exhaust, and the accumulated air volume in the rear of the pipe can still be large, bulb operation can become more marginal. Propagation rates of ~120 m/s are measured compared to full sonic in the test rig. So in mid-train pipe regions propagation slows. Modifications to either exhaust choke or bulb sizes made to suit the train length could be considered.
3. The pressure profile is usually fairly flat towards the rear of the brake pipe. When the brake pipe pressure in this region drops sufficiently to trigger the control valve, sonic propagation can occur as successive valves are triggered by bulb action alone. The results shown in Figure 46 from wagon #55 to wagon #92 (700+ m and within ~2 seconds) are indicative of sonic velocity. This is supported by the sonic velocities measured on the testing as shown in Figure 48, as the pressure drop rate used in the test rig approximated the rear of train behaviour.

6. Conclusions

Information arising from the literature review has shown a comparative difference in the Australian and American wagon brake systems in the way both assist the propagation of the pressure reduction rate. The American system has shown the development of the control valve evolved from using wagon lengths of 12 meters with 20 wagons to lengths of 9 to 27 meters and up to 150 wagons by the 1970's. Later control valve changes included the use of accelerated application valves and initial quick service valves both expelling portions of brake pipe air to the atmosphere.

The Australian wagon brake system by the 1970's went a different direction by holding a charge of brake pipe air in a quick service 'bulb' and then expelling this charge of air to the atmosphere when a brake release was made. The length of the Australian freight and mineral wagons has grown to similar lengths, with freight or mineral wagons having up to 19.5 meters of brake pipe. Developments in Australia have seen the number of wagons increase per train, and also the use of multi-coupled wagons with one control valve to operate brake pipe lengths of up to 39 meters.

The conclusion from the literature review is that the increase in the length between control valves and number of wagons in a rake adapted by Australian operators has not been fully supported with research and development of the control valve and/or other apparatus in the assistance of the propagation of the brake pipe reduction rate.

Results from the test rig show that when the brake pipe pressure drop rate is set close to the recommended minimum to operate a control valve, the size of the gulp progressively enlarges during propagation in a short pipe. Testing with more control valves is required to give an indication as to the size that gulps can progressively reach and when the air stored in a long pipe nullifies this effect. Further tests are also required using higher brake pipe pressure drop rates to fully investigate the mechanism of valve triggering from the local gulp verses the pressure drop from the brake pipe exhaust.

Branch pipes with larger internal diameters produce larger sized pressure reductions or gulps when connected to control valves via the pipe bracket. This conclusion is valid for comparing pipe diameters of 12 mm and 20 mm.

Branch pipes with different lengths but with the same internal diameter of 20 mm gave no measurable increase or decrease in the brake pipe local pressure reduction or gulp size when used with a pipe bracket connection. Branch pipes with shorter lengths but with the same internal diameter gave an increase in the brake pipe local pressure reduction or gulp size when used without a pipe bracket connection.

The quick service volume was shown to give a larger size gulp in the brake pipe when a control valve was connected without a pipe bracket. It is concluded that the restrictions to flow in the pipe bracket passageways reduce the size of the brake pipe gulp that can be achieved. This conclusion is further confirmed by the improvement gained by enlarging of the port in the rotary port plate in the isolation cock located in the pipe bracket.

Larger gulps were proved to be possible by testing an ‘experimental dummy bulb’ or ‘container’ as a bulb directly connected to the brake pipe. By removing the restrictive passageways caused by the pipe bracket and control valve, and connecting the ‘container’ direct to the brake pipe gave pressure gulps 113% larger than the 4.7 kPa reached when using the pipe bracket.

The investigations into the bulb fill times on both large and medium bulbs have shown that the passageways restrictions within the pipe bracket increase the time required to fill the bulb volume. In so doing these restrictions nullify any increase that could be obtained from large bulbs. The restrictions of the passageways in the pipe bracket can be therefore seen to be the major contribution to the gulp size. Improvements to propagation rate cannot be achieved with large bulbs combined with pipe brackets unless the pipe bracket passageways are modified.

From the above conclusions, the aims of this project has been met with conclusion of the literature review that a review and further research into the assistance of the propagation of the brake pipe reduction rate on Australian brake systems is needed.
The experimental work of this project has shown that with modifications to the brake system, improvements in the performance of the application delays can be achievable. The very simple modification of relocation the branch pipe connection from the pipe bracket to the control valve port will improve brake pipe propagation speeds.

7. Recommendations

Throughout the testing on the rig it has been shown that the restricted passageways in the pipe bracket has been responsible for a reduced gulp in the brake pipe. It has also been shown that larger branch pipe diameters can give a larger gulp in the brake pipe when connected to the pipe bracket. From the conclusions of the experiments performed on the test rig the following recommendations of focusing are suggested for further work.

1. Further investigations of branch pipes including:

    - The examination of results of gulp size in the brake pipe by having branch pipes connected directly to the control valve that eliminate or by pass the pipe bracket passageways.
    - Examine results of the gulp size and propagation rates from the effect of having a branch pipe larger than 20 mm internal diameter.

2. Further investigations of the pipe bracket including:

    - Improve the restriction of flow through the pipe bracket by enlarging the passageways.

3. Further investigations of the bulb including:

    - Investigate the possibility of using a choked exhaust of the bulb

- Investigate sizes of the bulb for bar coupled wagons controlled by one valve and multi-car packs with reduced numbers of control valves.
- Investigate the use of the Australian style Accelerated Application Valves (Westinghouse 1989) combined with the Australian style control valves.