ADDIS ABABA UNIVERSITY
INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

ANALYSIS THE EFFECT OF MALFUNCTIONING OF LOCOMOTIVE TRIPLE VALVE ON BRAKE TIME

A thesis Submitted to the school of Mechanical and industrial engineering in partial fulfillment of requirements for degree of Master of Science in Railway engineering (Rolling stock)

By

ADDISU SHIGUTE

ADVISOR: Mr. Tsegaye Feleke

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ABSTRACT

Triple valve malfunction (triple valve defect) causes an effect on braking distance, braking time and braking force. [10]. From those defects leakage through triple valve piston, sliding valve and graduating valve are taken for analyzing the effects of malfunctioning of locomotive triple valve on braking time. The defects during leakages through triple valve piston head, triple valve piston rod, sliding valve and graduating valve causes air pressure to decreases lower than air pressure during normal operation of triple valve. Maximum and minimum pressure losses during leakages through triple valve piston head, triple valve piston rod, sliding valve and graduating valve are taken for Analyzing braking distance, braking time and braking time. The mathematical modeling during pressure losses through those triple valve components are used for modeling block diagram by Simulink matlab during leakages through triple valve piston head, triple valve piston rod, sliding valve and graduating valve. The simulation is modeled by using Simulink matlab. The simulation result shows triple valve with maximum and minimum % of leakages increases braking time and braking distances, but decreases braking forces.

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Certainly, help and encouragement from others is always appreciated. This is to say that, this

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NOMENCLATURE

D_O	[m]	Outer diameter of seal
t_{sd}	[m]	Depth (thickness of seal)
d_p	[m]	Triple valve piston head diameter
d_r	[m]	Triple valve piston rod diameter
A_P	$[m^2]$	Effective area of triple piston head
A_r	$[m^2]$	Effective area of triple piston rod
P_{aux}	[Pa]	air pressure from auxiliary reservoir
F_b	[N]	Force applied on triple piston head
F_r	[N]	Force applied on triple piston rod
P_{lp}	$[P_a]$	pressure loss from triple piston head
P_{lpr}	[Pa]	pressure loss from triple piston rod
A_{sw}	$[m^2]$	Area of seal worn
P_{lsv}	$[P_a]$	Air pressure loss from sliding valve
P_{lgv}	$[P_a]$	Air pressure loss from graduating valve
P_{lpmax}	$[P_a]$	max. Air pressure losses through triple valve piston head
P_{lprmax}	$[P_a]$	max. Air pressure losses through triple valve piston rod
P_{lsvmax}	$[P_a]$	max. Air pressure losses through sliding valve
P_{lgvmax}	$[P_a]$	max. Air pressure losses through graduating valve

M	[Kg]	mass of vehicle
T	[N]	Sum of all forces that are contributed on braking
D	[N]	Drag force
Cd		Drag coefficient
t_b	[Se]	Braking time
S_b	[m]	Braking distance
V_O	$[\frac{m}{s}]$	Vehicle velocity
F_b	[N]	Braking force
T_f	[N]	Frontal axle force
T_r	[N]	Rear axle force
A_{bcp}	$[m^2]$	Area of brake cylinder piston head
ρ	$[\frac{Kg}{m^3}]$	Air density
TVPh		Triple valve piston head
TVPr		Triple valve piston rod
SV		Sliding valve
GV		Graduating valve
ERC		Ethiopian Railway Corporation

CHAPTER ONE

1. Background

Railways that fulfill the definition of Dr.Lewis existed as far backs 6th century BC. The Greek Diolkoswasa railway with a track made of stone, 6km in length across the peoplopense, used for transporting ships until the 9th century AD. The agricolasdere metallica dates the extensive use of railways with wooden rails and vehicles to around the 15th century. Although they are of great technical interest their application was very much limited to the mining industry and had short life time. Longer and were the developed.

Following the early birth of the railways ideas, the birth of modern railway is linked to the innovation of steam engines whereas the enormous development of the railway in the 20th century is very much related to electrification of railway lines. The first electric locomotives was manufactured in the last third of 19th century, while the first diesel locomotives built at the beginning of the 20th century. The speeds of diesel locomotives are much lower than electric locomotives. However, in areas where electrification isn't available. Diesel locomotives have played important roles. On the other hand, due to the rising need for speed and environmental issues the electric locomotives are on the fore front of the railway industry throughout the world despite the very high cost of infrastructure in electrifying the lines.

Railway in Ethiopia started in 1901 when the train with Swiss made diesel engines commenced operation on July 22 from Djibouti to Dounle which after year and half was extended to Dire dawa. The bogie wagons were some with four axle‘s weighing 10 tons and carrying 22 tons.

1.2 Introduction

A moving train contains energy, known as kinetic energy, which needs to be removed from the train in order to cause it to stop. The simplest way of doing this is to convert the energy into heat. The conversion is usually done by applying a contact material to the rotating wheels or to discs attached to the axles. The material creates friction and converts the kinetic energy into heat. The wheels slow down and eventually the train stops. The material used for braking is normally in the form of a block or pad.

The vast majority of the world's trains are equipped with braking systems which use compressed air as the force to push blocks on to wheels or pads on to discs. These systems are known as "air brakes" or "pneumatic brakes". The compressed air is transmitted along the train through a "brake pipe". Changing the level of air pressure in the pipe causes a change in the state of the brake on each vehicle. It can apply the brake, release it or hold it "on" after a partial application. The system is in widespread use throughout the world.

1.2.1 Different types of train brake

1.2 .2 Electro-pneumatic brakes

That has an electrical command while compressed air is used to increase the pressure in the brake cylinders of each vehicle to apply the brake blocks or pads for generating braking forces.

1.2.2Hydraulic brakes

Which act using hydraulic oil and, depending on the achievement of braking forces, there may be hydrostatic, when is due to oil pressure increasing or hydrodynamic when the kinetic energy of the vehicle is converted in the rotor of a hydraulic pump in heat which is dissipated through the oil cooling system.

1.2.3 Disc brakes

The applied brake force acting on the brake caliper pushes the brake pads against the rotating disc which in turn constrains the rotation of the wheel.

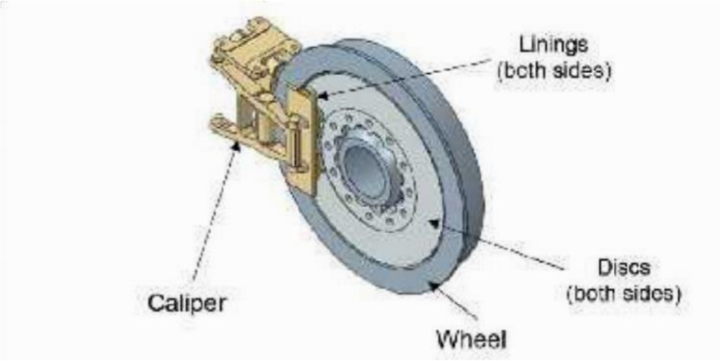

Figure 1 disc brake [12]

1.2.4 Tread brakes

In this type of braking, block brakes are pressed against the wheels that the train could either decelerated or stopped if necessary.

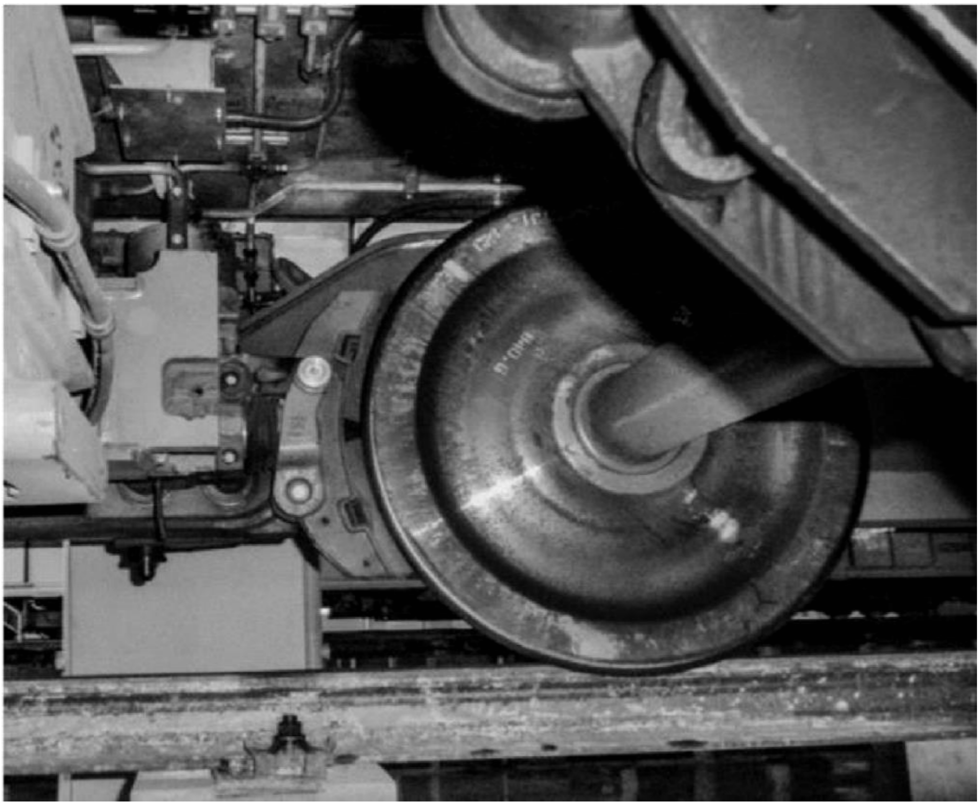

Figure 2 Tread brake assembly [11]

1.3 Parts of the Air Brake System

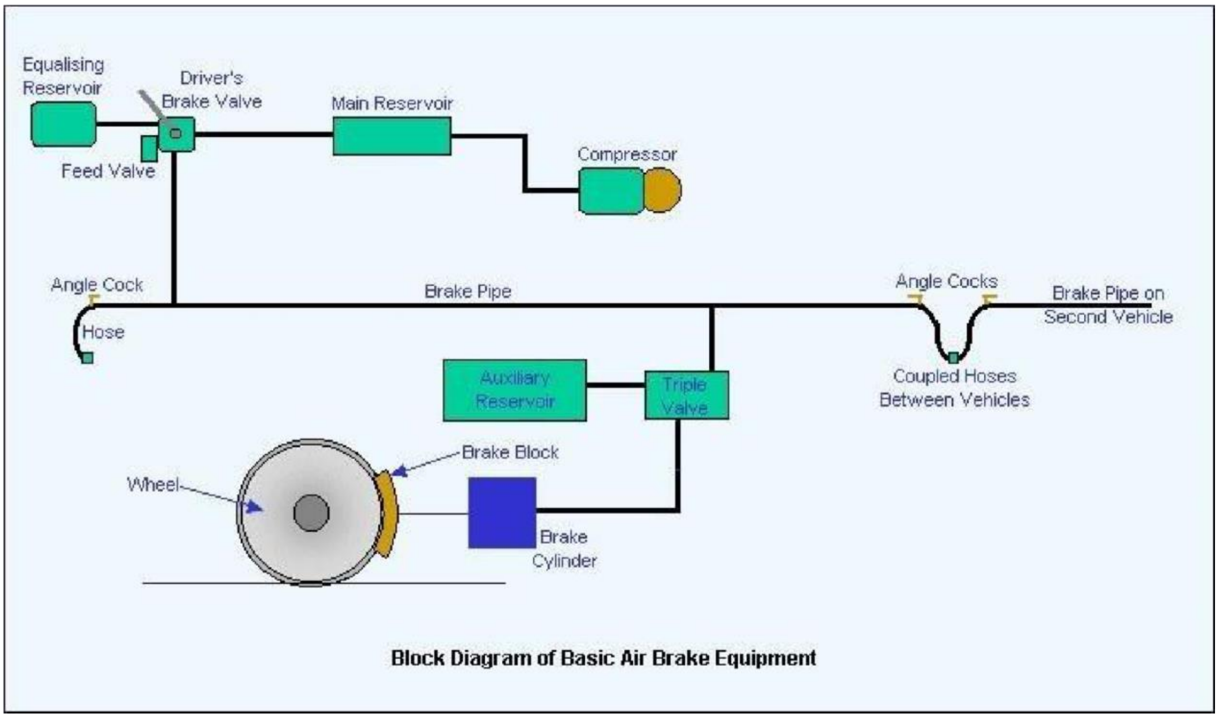

Figure 3 the Principal Parts of the Air Brake System [9]

1.3.1 Compressor

The pump which draws air from atmosphere and compresses it for use on the train. Its principal use is for the air brake system, although compressed air has a number of other uses on trains.

1.3.2 Main Reservoir

Storage tank for compressed air for braking and other pneumatic systems.

1.3.3 Driver's Brake Valve

The means by which the driver controls the brake. The brake valve will have (at least) the following positions: "Release", "Running", "Lap" and "Application" and "Emergency". There may also be a "Shut Down" position, which locks the valve out of use.

The "Release" position connects the main reservoir to the brake pipe. This raises the air pressure in the brake pipe as quickly as possible to get a rapid release after the driver gets the signal to start the train.

In the "Running" position, the feed valve is selected. This allows a slow feed to be maintained into the brake pipe to counteract any small leaks or losses in the brake pipe, connections and hoses.

"Lap" is used to shut off the connection between the main reservoir and the brake pipe and to close off the connection to atmosphere after a brake application has been made. It can only be used to provide a partial application. A partial release is not possible with the common forms of air brake, particularly those used on US freight trains.

"Application" closes off the connection from the main reservoir and opens the brake pipe to atmosphere. The brake pipe pressure is reduced as air escapes. The driver (and any observer in the know) can often hear the air escaping.

Most driver's brake valves were fitted with an "Emergency" position. Its operation is the same as the "Application" position, except that the opening to atmosphere is larger to give a quicker application.

1.3.4 Feed Valve

To ensure that brake pipe pressure remains at the required level, a feed valve is connected between the main reservoir and the brake pipe when the "Running" position is selected. This valve is set to a specific operating pressure. Different railways use different pressures but they generally range between 65 and 90 psi (4.5 to 6.2 bar).

1.3.5 Equalizing Reservoir

This is a small pilot reservoir used to help the driver select the right pressure in the brake pipe when making an application. When an application is made, moving the brake valve handle to the application position does not discharge the brake pipe directly, it lets air out of the equalizing reservoir. The equalizing reservoir is connected to a relay valve (called the "equalizing discharge valve" and not shown in my diagram) which detects the drop in pressure and automatically lets air escape from the brake pipe until the pressure in the pipe is the same as that in the equalizing reservoir.

The equalizing reservoir overcomes the difficulties which can result from a long brake pipe. A long pipe will mean that small changes in pressure selected by the driver to get a low rate of braking will not be seen on his gauge until the change in pressure has stabilized along the whole train. The equalizing reservoir and associated relay valve allows the driver to select a brake pipe pressure without having to wait for the actual pressure to settle down along a long brake pipe before he gets an accurate reading.

1.3.6 Brake Pipe

The pipe running the length of the train, which transmits the variations in pressure required to control the brake on each vehicle. It is connected between vehicles by flexible hoses, which can be uncoupled to allow vehicles to be separated. The use of the air system makes the brake "fail safe", i.e. loss of air in the brake pipe will cause the brake to apply. Brake pipe pressure loss can be through a number of causes as follows:

- A controlled reduction of pressure by the driver
- A rapid reduction by the driver using the emergency position on his brake valve
- A rapid reduction by the conductor (guard) who has an emergency valve at his position
- A rapid reduction by passengers (on some railways) using an emergency system to open a valve
- A rapid reduction through a burst pipe or hose
- A rapid reduction when the hoses part as a result of the train becoming parted or derailed.

1.3.7 Angle Cocks

At the ends of each vehicle, "angle cocks" are provided to allow the ends of the brake pipe hoses to be sealed when the vehicle is uncoupled. The cocks prevent the air being lost from the brake pipe.

1.3.8 Coupled Hoses

The brake pipe is carried between adjacent vehicles through flexible hoses. The hoses can be sealed at the outer ends of the train by closing the angle cocks.

1.3.9 Brake Cylinder

Each vehicle has at least one brake cylinder. Sometimes two or more are provided.
The movement of the piston contained inside the cylinder operates the brakes through links called "rigging". The rigging applies the blocks to the wheels. Some modern systems use disc brakes.

The piston inside the brake cylinder moves in accordance with the change in air pressure in the cylinder.

1.3.10 Auxiliary Reservoir

The operation of the air brake on each vehicle relies on the difference in pressure between one side of the triple valve piston and the other. In order to ensure there is always a source of air available to operate the brake, an "auxiliary reservoir" is connected to one side of the piston by way of the triple valve. The flow of air into and out of the auxiliary reservoir is controlled by the triple valve.

1.3.11 Brake Block

This is the friction material which is pressed against the surface of the wheel tread by the upward movement of the brake cylinder piston. Often made of cast iron or some composition material, brake blocks are the main source of wear in the brake system and require regular inspection to see that they are changed when required.

Many modern braking systems use air operated disc brakes. These operate to the same principles as those used on road vehicles.

1.3.12 Brake Rigging

This is the system by which the movement of the brake cylinder piston transmits pressure to the brake blocks on each wheel. Rigging can often be complex, especially under a passenger car with two blocks to each wheel, making a total of sixteen. Rigging requires careful adjustment to ensure all the blocks operated from one cylinder provide an even rate of application to each wheel. If you change one block, you have to check and adjust all the blocks on that axle.

1.3.13 Triple Valve

Triple valve is the most important functional component of the air brake system and is also sometimes referred to as the heart of the air brake system.

The operation of the brake on each vehicle is controlled by the "triple valve", so called because it originally comprised three valves - a "slide valve", incorporating a "graduating valve" and a "regulating valve". It also has functions - to release the brake, to apply it and to hold it at the current level of application. The triple valve contains a slide valve which detects changes in the brake pipe pressure and rearranges the connections inside the valve accordingly.

Triple valve either:

- the air Recharges the auxiliary reservoir and opens the brake cylinder exhaust,
- Closes the brake cylinder exhaust and allows the auxiliary reservoir air to feed into the brake cylinder
- Or holds pressures in the auxiliary reservoir and brake cylinder at the current level.

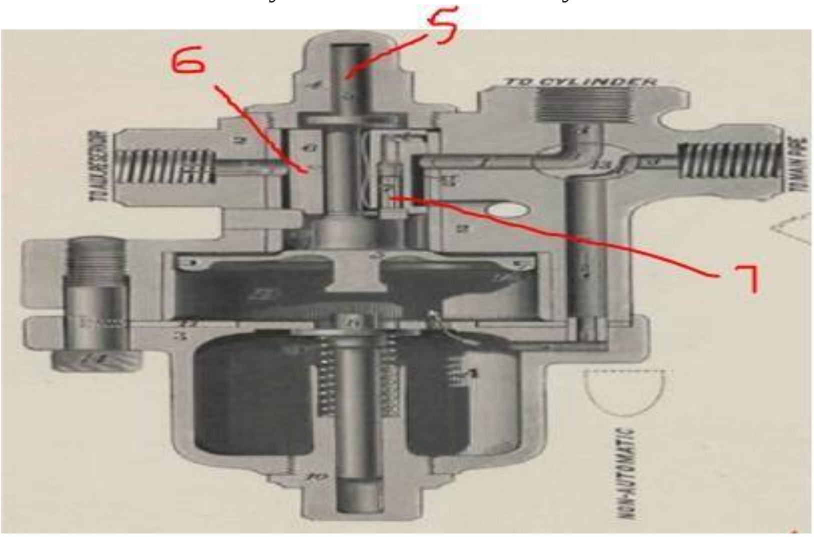

Figure 4 triple valve sectional views [22]

From this figure no.5 is triple valve piston, no.6 is sliding valve andno.7 is graduating valve

1.4 Main parts of control valve (Triple valve) diagram

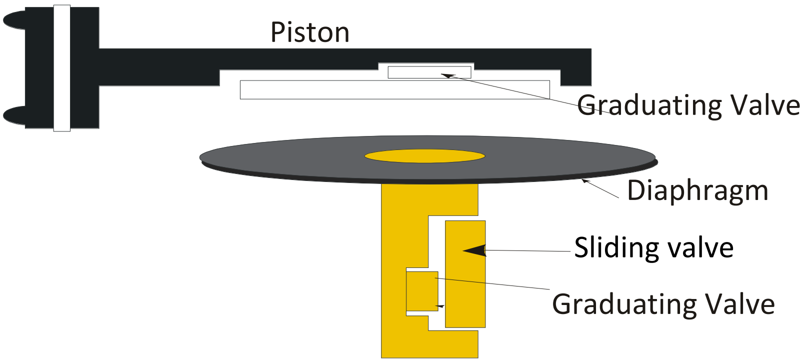

Figure 5 Main parts of triple valve [18]

1.4.1 Piston

The piston is the heart of the control valve. The service portion has a piston, slide valve, graduated valve and a slide valve seat. The pistons are mounted vertically using a rubber diaphragm as a seal. The top or head of the piston is round and has a rubber diaphragm attached. The main stem of the piston is also round but may have some flat areas in which to attach the slide and graduated valves. The shape of the piston has a direct relationship to its movement, it allows air to flow around the stem and allows free movement of the piston. The main function of triple piston is to open & to close the feed groove & also controlling the movement of slide valve & graduating valve

1.4.2 Slide Valve

Slide valves are attached to the piston inside the control valve. The sliding valve moves depending upon the movement of the piston but have a certain amount of slack in their movement. Slide valves have numerous holes in them to allow air to move from one area to another.

1.4.3 Graduating Valve

Graduating valves are flat valves inserted into an opening in the stem of the piston. They are also flush against the slide valve. They have small opening in them to allow passage of air. When the piston moves the graduated valve moves, this causes the ports to align on the slide valve allowing air to flow resulting in a valve reaction. Graduating valve operates with the conjunction with slide valve by pin attached to the stem of triple piston. Opens & closes a port in the slide valve to control the flow of air from auxiliary reservoir to the brake cylinder when in the applied position.

1.4.4 Feed grooves

Provide a connection between the pipe and the auxiliary reservoir when triple valve is in the release position and controls the rate at which the auxiliary reservoir is charged.

1.4.5 Diaphragms

Diaphragms are rubber separators attached to the center of the piston and the outer edge of the valve casting. This provides a positive seal on both sides of the piston resulting in the formation of a cavity on both sides of the diaphragm. Pressure exerted on one side of the diagram causes the piston to move resulting in the slide valve and graduated valve moving as well.

1.4.6 Springs

Springs are used to provide a resistant force to the effects of an air pressure balance. Attached to the end of a piston to provide a specific pressure resistance as indicated in psi.

1.5 Working principle of Triple valve

1.5.1 Braking application

At a time of braking application the air pressure from the pipe is decreased and but the air pressure entered to the brake cylinder is increased. This is done during the driver put the valve on the braking position. At this time the triple piston moves to the left extreme position and the graduating valve which is connected to the triple piston is closed the exhaust port of slide valve and also opening the port which is connected to the brake cylinder.

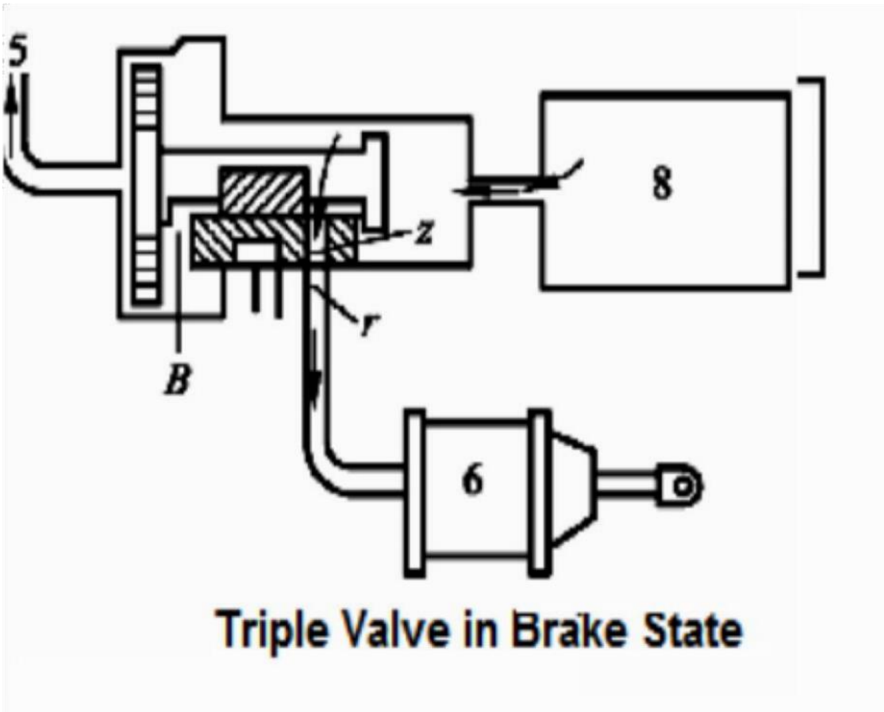

Figure 6 triple valve in brake state

5 brake pipe, 6 brake cylinder 8 auxiliary reservoir

1.5.2 Release application

During release application the triple piston moves to right extreme position and also the graduating valve moves to the right extreme position to open the slide valve exhaust port and closes slide valve port which is connect to brake cylinder.

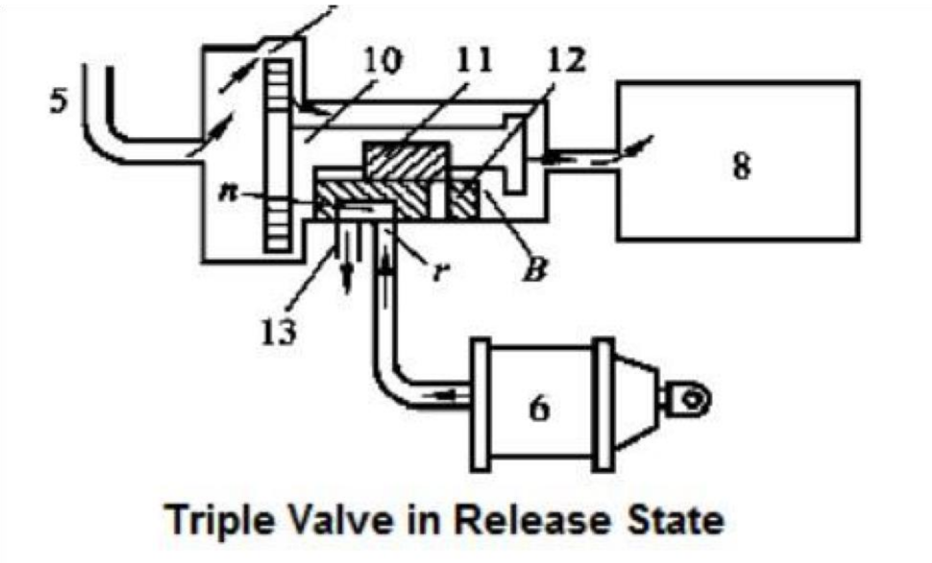

Figure 7 triple valve in release state

10 triple valve main piston, 11 graduating valve, 12 sliding valve, 13 sliding valve exhaust port

1.6 Defect of Triple valve [10]

1.6.1 Brake applies quick action

The triple applies brake quick action during service application because of: (1) a dirt condition of the triple valve or to a weak or broken graduating spring

1.6.2 Dirty Triple valve

A dirty triple valve is the most frequent cause of brake applying quick action during a service application. The gum & dirt will hold the triple piston when the first brake pipe reduction is made, but when the difference of pressure between the auxiliary and brake pipe is great enough to loosen the piston from the gum & dirt to travel rapidly to emergency position & applying quick action brake. The heavy local reduction of brake pipe pressure at this triple valve will cause the other to apply quick action.

1.6.3 Weak or broken graduating spring

A weak or broken graduating spring will cause trouble on short train but may cause trouble on long one. When the train is short, the brake pipe volume is smaller than when the train is long , and pressure can reduce through the brake pipe exhaust port at the brake valve faster than auxiliary- reservoir pressure can be reduced the service port in the triple valve. When this difference of pressure is great enough, auxiliary reservoir pressure will force the triple valve piston & slide valve to emergency position & apply the brake quick action. On long train, where the brake pipe volume is greater, brake pipe pressure may not reduce faster through the brake pipe exhaust port at the brake valve and the quick service ports in the triple valves than auxiliary reservoir pressure can reduce through the service port z in the triple valve: consequently, a weak or broken graduating spring may cause no trouble. But, if the train is not very long, a triple valve with a weak or broken graduating spring may assume full-service position that would otherwise assume quick service position.

1.6.4 Blow at Triple valve Exhaust port

A blow the triple exhaust port may be caused by either brake pipe or an auxiliary reservoir leak. The brake pipe leak may due to a defective emergency valve or a leak past the gasket. An auxiliary leak may be caused by leaky slide valve leaky gasket allowing air to feed into passage, or leaky auxiliary tube.

1.6.5 Leaky check valve case gasket

If the check valve gasket leaks, it will cause a blow at the triple valve exhaust port when the brakes are released and the triple is in release position, and when the brakes are applied with alight application, because of leak brake to apply is hard.

1.6.6 Graduating valve leaking

If the graduating valve leaks, very apt to cause the brake to release when applied in light application .this values controls the passage of air from the auxiliary reservoir to the brake cylinder and in case not entirely close service port when triple piston assumes lap position, auxiliary reservoir pressure will continue to pass the brake cylinder until brake pipe pressure exceeds auxiliary reservoir pressure sufficiently to move the triple piston to release position. If the graduating valve leaks so that brake pipe air can feed through the quick service ports into the brake cylinder, when the triple is in quick service lap position, permitting the brake pipe pressure to equalize with the brake cylinder pressure: also the leak cause delay of brake release.

1.6.7 Quick –service ports blocked up

If the quick service ports in the slide valve seat should become blocked or obstructed , it would in the a failure of the triple thus affected to vent brake –pipe air into the brake cylinder during a service applications ,which on the initial service reductions ,would cause the loss of slight amount of brake –cylinder pressure . In a long train no material detriment to the action of brakes will be observed if only a few of triples in the train have their quick service ports blocked, & no attempt should be made on the road to remedy such defect. This defect may be detected while charging empty auxiliary reservoir by the absence of the buzzing noise caused by brake –pipe air feeding past the check –valve

1.6.8 Dirt strainer

A dirt strainer may cause the auxiliary reservoir to charge very slowly.

1.6.9 Slide valve leaking

A leaky slide valve will usually cause a blow at the triple valve exhaust port whether the brake is applied or not, and will tend to release the brake when applied.

1.6.10 Emergency valve leaking

With brakes released a leak in the emergency valve will cause a constant blow at the triple valve exhaust port, accompanied frequently by buzzing noise in the triple valve. When the brakes applied with alight application such a leak will allow brake pipe & brake cylinder pressure to equalize and this cause wheels to slide especially on along train having a large volume of brake pipe air with which to equalize. If the emergency piston become cocked, or stuck in cylinder causing a constant blow & a large waste of air to atmosphere through exhaust port of triple.

1.7 Summary for the causes of malfunction of triple valve

- Broken graduating spring: - due to the spring which pushes the main piston (triple piston) is broken.
- Dust (external material which entered to the valves to restrict the movement of the triple piston.
- Dirt retainer (due to improper work of filter)
- Leakage through triple piston: - leakage through triple piston is due to diaphragm (seal) wear.

- Leakage due to piston packing ring and proper fit of piston against the end of slide valve bushing
- Leakage through graduating valve :- when there is a problem in fitting of pin which attached to triple piston
- Leakage through slide valve [10]

1.8 Statement of the problem

Triple valve is essential part of automatic air brake equipment. Malfunctionality of triple valve components causes the following problems during braking time: Disorderness of braking and releasing (time lag), decreasing braking force & increasing braking distance.

1.9 Objective of research

1.9.1 General Objective

The general objective of this research is to analyze the effect of locomotive triple valve malfunction on brake time using Simulink mat lab by taking main components of triple valve such as triple valve piston, sliding valve and graduating valve. Malfunction of those components causes a major effect on braking system.

1.9.2 Specific objective

To analyze braking distance and to simulate braking distance with Simulink mat lab during malfunction of triple valve specifically during triple valve leakage.

To analyze braking time and to simulate braking time with Simulink mat lab during malfunction of triple valve specifically during triple valve leakage.

To analyze braking force and to simulate braking force with Simulink mat lab during malfunction of triple valve specifically during triple valve leakage.

Comparing braking distance, braking time and braking force with maximum and minimum triple valve leakage with that of without leakage.

1.10 Research methodology

Research methodology as its name indicates is the method used to solve the problem identified in the statement of problem. So the methodology used to accomplish the specified problems are:-

- By browsing different books, researches done before on electro pneumatic brake triple valve malfunction.

- Procedures [understanding the triple valve operation for modeling mathematical equation & using those mathematical equation for modeling Simulink mat lab .Simulating the model for displaying the result and finally comparing the simulated result at normal triple valve operation (i.e. without lose) and at abnormal triple valve operation (i.e. due to lose).
- Finally the general simulation output of braking time & braking distance at normal operation of triple valve (i.e. without lose) is compared with the abnormal operation of triple valve(i.e. due to lose) to see the difference in both condition.

1.11 Scope of research

Train Triple valve has many parts. From those parts which plays major task during braking are taken .So this paper will not cover whole parts of triple valve components .From those parts sliding valve, triple valve main piston ,triple valve piston rod ,graduating valve and seal(diaphragm) are taken. For triple valve main piston and for triple valve piston rod area of seal wear is considered in order to calculate the pressure loss on triple valve main piston head and triple valve piston rod .other components such as gasket is not included.

For sliding valve and graduating valve assuming % leakage according to control valve (TV) leakage classification from literature review. And for simulating braking distance, braking force and braking time during braking application, also area of brake cylinder piston is taken from literature review and assumed rigging effect is used. This paper is limited to simulation of braking distance, braking force and braking time during maximum and minimum air pressure leak through triple valve components with that of normal operation of triple valve components (i.e. without triple valve leakage).

1.12 Limitation of the study

This paper has done by browsing different literatures from internet. Some of triple valve component parameters and specifications are not found within compiled document rather than different literature review.

1.13 Thesis organization

In chapter one (1) the background of train general braking systems and types of train braking system are discussed. Particularly from automatic air braking systems triple valve components and function of triple valve is discussed. In this chapter the problem of the statement and the main and specific objectives of analyzing the effect of malfunction of locomotive triple valve during braking time with simulink-matlab are also discussed clearly. In Chapter two (2) literature reviews on analyzing effect of locomotive malfunction of triple valve is reviewed from related literature.

In chapter three (3) important data and equations are collected for the analyzing effect of locomotive malfunction of triple valve.

In chapter four (4) the block diagram for maximum and minimum triple valve leakage and block diagram without triple valve leakage is modeled and simulated in mat lab Simulink modeling.

In chapter five (5) the simulated result in chapter four is discussed clearly with the help of diagrams. In this chapter the simulated results are compared with the actual calculated data during analyzing.

In chapter six (6) the whole research is concluded shortly and briefly. And there is a future work recommended to be done by anyone who has an interest on this field of specialization.

CHAPTER-2

2 LITERATURE REVIEW

B., I stock, V., Szente and J., Vad[2] are showing the experimental and numerical investigation on the dynamic behavior of pneumatic pressure regulator valve of electro pneumatic brake. The main aim of those guys were to show the leakage through the valve at different cases especially when the seal wear (making a gap) between a valve.

The first step of PRV analysis was to measure the characteristics of the valve for leakage condition. During the measurement, a supply pressure reservoir of constant (ambient) temperature was connected to the pressure inlet port. A ball valve has been connected to the pressure outlet port to set the amount of leaking mass flow rate. The p_r and p_s pressures have been measured using pressure transducers commonly used in electro-pneumatic brake systems. Because of the relatively small leaking mass flow values and relatively large volume of the supply reservoir, the p_s pressure of the reservoir has practically remained at a constant value during the measurements.

The PRV behavior has been tested experimentally for three different (“low”, “medium” and “high”) leaking mass flow rates. The results of the measurements are presented in figure7 in dimensionless form. In order to make the results dimensionless, the actual absolute p_r pressure has been divided by the reservoir pressure, while the actual time has been divided by the time constant t_0 (time necessary for pressure reduction to 0 bar (rel) with the initial pressure gradient).

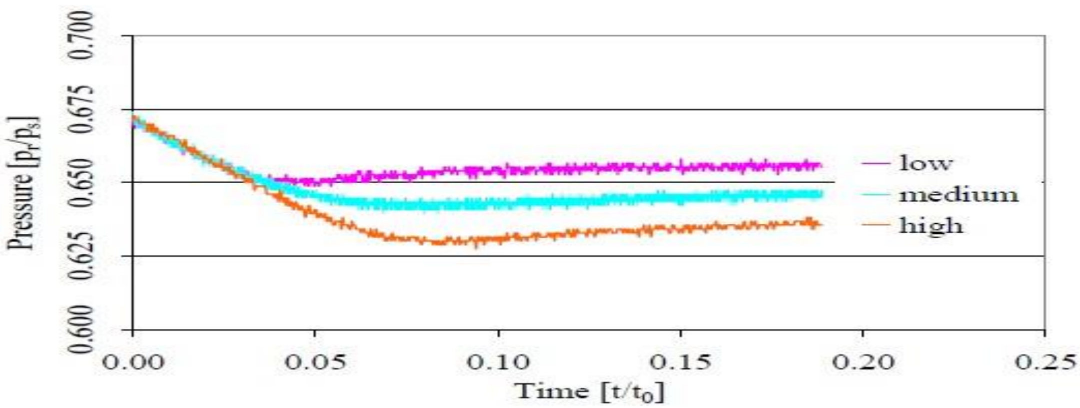

Figure 8 measurement result for the three test cases

As the figure suggests, the measured pressure history can be separated to three regions:

Immediately after the opening of the ball valve (at time instance 0 s), p_r starts to decrease.

During this process, the PRV remains closed. After a delay, the PRV opens.

This figure shows as the leakage amount increases air pressure which used to open the valve is decreased ,but braking time is increased on those three leakages cases (i.e. in low ,medium and high leakage cases)

Electro pneumatic brake system has different braking components. From those components triple valve is the part which act as heart of braking system. Leakage of the valve is caused by sealing problem. As result this brings the pressure loss through the valve.

Srivatsan Ramarthnam, Sandeep Dhar, Swaroop Darbha and K.R. Rajagopal [15] have modeled air brake system with leaks.

The main aim of those researchers are to compare the air brake system without leak to that of with leak (i.e. In the case of leaks taking the effective area to see the pressure lose) and also they are taking supply pressure and effective area for leaks to comprised it as input to the model.

Air brake defect caused by leakage through the braking components (i.e. in such as triple valve) affect braking performance so this problem causes the braking pressure to decrease and increasing time required to attain so this resulting longer braking distance to taken in Place.

Priya Stalling [16] is done a research on electronic control air brake system for high speed trains. The main aim of this researcher is to show the influence of pressure level on braking system desired output. From his finding air pressure during leakages though braking components decreasing braking performance. Braking distance and braking time increases when amount of air pressure decreased during air leaks through braking components.

Saeed Abu Alyazeed Albatlan [14] is done a research on performance of air brake combination valve. This person focused on performance of braking system due to different cases. He studies those which decreases the braking performances. According to his study leakages through braking components such as braking valve increasing braking time and braking distance.

Swaroop Dharba and K.R. Raja gopal [13] have done a research on development of diagnostic system for air brake system for air brake trucks. The main aims of those researchers are to enhance the safety trucks by developing diagnostic system that assess the health of brake system. This research has three stages the 1st stage develop leak detection algorithm based on mathematical model that predicts the evolution of pressure in braking components. On their second stage they estimate the piston movement stroke in absence of leak. In their third stage they included the development, experimental implementation, testing and evaluation of diagnostic in presence of leaks.

Shankar Ram Coimbatore Subramanian [23] has done a dissertation on a diagnostic system for air brakes in commercial vehicles. The main aims of this guy is to shows diagnostic system for air brakes in commercial vehicles. According his study possible faults such as leaks through valves have an effect on braking system. Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances.

2.1 Conclusion

From those researchers air pressure drops during leakages through braking components such as control valve decreases braking force and increasing braking time and braking distance.

Chapter 3

3 Analyzing effect of locomotive malfunction of triple valve on braking time

Analyzing is done when air leaks through

- Triple valve piston head
- Triple valve piston rod
- Sliding valve and
- graduating valve

3.1 Triple valve main piston valve

3.1.1 Seal wear

Triple valve piston head and triple valve piston rods are surrounded by seals. Seals are worn by different cases:-

- collision of vehicle
- Vibration of vehicle
- Improper adjustment

During the above causes the repetitive force applied on the seal and these repetitive forces causes the seal to wear. [5],[6],[11].

Outer diameter and depth of seal are 78.6mm and 22 mm respectively [19] [26]

Figure 9 Diaphragm (seal)

Table 1 outer diameter and depth specification of diaphragm

OD(outer diameter of seal)	78.6m m
Depth(thickness of seal)	22mm

Assumption

Taking small number decreased from the normal thickness of seal e.g. 0.01mm, 0 .02mm, 0.03mm, 0.05mm, 0.1mm, 0.2mm, 0.4mm and 0.5mm for calculating seal worn area.

Table 2 thickness of seal which is decreased by small number because of wearing

Decreased amount of number from thickness	Thickness of seal (t_{sd})
0mm	22mm
0.01mm	21.99mm
0.02mm	21.98mm
0.03mm	21.97mm
0.04mm	21.96mm
0.05mm	21.95mm
0.1m	21.9mm
0.2mm	21.8mm
0.3mm	21.7mm
0.4mm	21.6mm
0.5mm	21.5mm

3.1.2 Pressure loss during releasing application

Triple valve main piston moves to right extreme position during release application but, because of leakage air pressure decreased in some amount and this causes triple valve piston to decrease the maximum movement stroke .[7]

$$Do = t_s + d_p \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 3.1$$

Do = outer diameter of seal
dp= triple piston head diameter

t_s = thickness of seal

$$F_{p=P*AP} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .3.2$$

$$A_{p=\pi} \frac{d_{p^2}}{4} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .3.3$$

π=3.14

A_p= Effective area of triple piston head

This area is an area on which force is applied in order to extending the piston to the right during releasing application.

P is air pressure reduced through brake pipe for charging auxiliary reservoir during releasing application. The triple valve main piston is extended to the right when air pressure from brake pipe is applied on triple valve main piston head. P=600KPa [7]

Fp=Force applied on effective area of triple piston head

Force applied on effective area of triple piston head pushes triple valve main piston to the right .This force created when air pressure from brake pipe is applied on effective area of triple valve main piston head.

$$F_{P=600*3.14\frac{(0.040)^2}{4}=753.6KN}$$

$$P_{lp}=\frac{F_p}{A_{sw}} \quad \ldots 3.4$$

P_{lp} =pressure loss on piston head due to seal problem

During seal worn air pressure loss happen on triple valve main piston head

A_{sw}=Area of seal worn

Area of seal worn is an effective area which losses the air during releasing application.

$$A_{sw} = \frac{\pi\left(d_p + t_{sd}\right)^2}{4} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.5$$

t_{sd}= decreased thickness of seal.

Values of decreased thickness of seal is expressed in table 1

dp=diameter of triple valve main piston head

dp = 0.040m [12]

Table 3 area of seal worn from triple valve piston head

Decreased thickness of Seal t_{sd} (m)	Area of seal worn $A_{sw}(m)^2$= $\pi\frac{(d_{p+t_{sd}})^2}{4}$
0.022m	0.0030175
0.02199m	0.0030165
0.02198m	0.0030155
0.02197m	0.0030146
0.02196m	0.0030136

0.02195m	0.0030126
0.0219m	0.0030078
0.0218m	0.002998
0.0217m	0.002988
0.0216m	0.0029787
0.0215m	0.002969

Table 4 air pressure loss from triple piston head position

$A_{sw}(m)^2 = \frac{\pi(d_p + t_{sd})^2}{4}$	$P_{lp} = \frac{F_p}{Asw}$, $F_{P=753.6KN}$
0.0030175	249.7kpa
0.0030165	249.8kpa
0.0030155	249.9kpa
0.0030146	249.98kpa
0.0030136	250kpa
0.0030126	250.06kpa
0.0030078	250.5kpa
0.002998	251.4kpa
0.002988	252.2kpa

0.0029787	252.3kpa
0.002969	253.8kpa

3.1.3 Pressure loss during braking application

When the driver put the valve on braking position the triple valve piston moves from right extreme position to the left extreme position. Since triple valve piston and graduating valves are connected by pin, both are sliding together. During this application the port which is connected to atmosphere is closed and the port from brake cylinder side is open. Connection problem of graduating valve with that of triple valve piston and sliding valve causes air pressure to decrease. [7] [8]

$$D_O = t_s + d_r \ldots\ldots\ldots 3.6$$

D_O = outer diameter of seal

d_r= triple valve piston rod diameter

t_s= thickness of seal

π=3.14

$$F_r = P_{aux} * A_r \ldots\ldots\ldots 3.7$$

A_r = Effective area of triple valve piston rod

This area is an area on which force is applied in order to retracting the piston to the left during braking application.

Diameter of main valve piston rod = 0.008m [12]

$$A_r = \pi \frac{d_{r^2}}{4} \ldots\ldots\ldots 3.8$$

P_{aux}= air pressure from auxiliary reservoir

P_{aux} is an air pressure from auxiliary reservoir which pushes the triple piston rod to the left extreme position. Paux is used for opening and closing ports of sliding valves during braking application. Air pressure of auxiliary reservoir is passing through sliding valve for applying a brake on brake cylinder piston.

$$P_{aux=600KPa} \quad F_{r=} \quad Paux * A_r = 600KPa * \pi \frac{0.008^2}{4} = 30.2KN$$

$$P_{lpr} = \frac{F_r}{A_{sw}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 3.9$$

P_{lpr} =pressure loss on piston rod due to seal problem

Pressure loss on triple valve main piston rod is occurred at a time when circular seal surrounded the piston rod is worn.

Area of seal worn is an effective area which losses the air during braking application.

$$P_{lpr} = \frac{4(F_r)}{\pi(d_r+t_{sd})^2} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 3.10$$

Assumption

Decreasing very small number from original thickness of seal as that of triple valve piston rod original thickness of seal is 22mm. [19]

Table 5 thickness of seal decreased from piston rod position

Decreased amount of number from normal thickness of seal	Thickness of seal decreased (t_{sd})
0mm	22mm
0.01mm	21.99mm
0.02mm	21.98mm
0.03mm	21.97mm

0.04mm	21.96mm
0.05mm	21.95mm
0.1m	21.9mm
0.2mm	21.8mm
0.3mm	21.7mm
0.4mm	21.6mm
0.5mm	21.5mm

Table 6 areas of seal worn of triple valve piston rod

Decreased thickness of seal $tsd\ (m)$	Area of seal worn $A_{sw} = \frac{\pi(d_r+t_{sd})^2}{4}$
0.022m	0.0007068
0.02199m	0.0007063
0.02198m	0.0007059
0.02197m	0.0007054
0.02196m	0.0007049
0.02195m	0.0007045
0.0219m	0.0007021
0.0218m	0.0006974
0.0217m	0.0006927
0.0216m	0.0006881
0.0215m	0.0006834

Table 7 pressure loss due to seal of triple valve piston rod worn

Area of seal worn(Asw) = $\pi\frac{(d_{r+t_{sd}})^2}{4}$	$P_{lpr=\frac{F_r}{A_{sw}}}$, $F_{r=}$ 30.2KN
0.0007068	42.72KPa
0.0007063	42.75 KPa
0.0007059	42.78 KPa
0.0007054	42.81KPa
0.0007049	42.84 KPa
0.0007045	42.76KPa
0.0007021	43.01KPa
0.0006974	43.30 KPa
0.0006927	43.59 KPa
0.0006881	43.88 KPa
0.0006834	44.19 KPa

3.2 Pressure loss due to sliding valve leakage

Minimum 5% of air pressure leaks through sliding valve from normal air pressure during malfunction. Sliding valve has two ports. The first port is the one which is connected to the brake cylinder and the second one is the one which is connected to the atmosphere. During braking application the port which is connected to the brake cylinder is opened and air pressure is passed through it. [20]

Standard air pressure reduced from train pipe is 600kpa [7] P_{lsv}=air pressure loss amount due to sliding valve leakage

Table 8 air pressure loss amount due to sliding valve leakages

Assumption % of leakage during sliding valve	P_{lsv}=%l leakage*600KPa= air pressure loss amount due to sliding valve
0.5	3
5	30
10	60
15	90

3.3 Pressure loss amount due to graduating valve leakage

Minimum 0.1% of air pressure leaks through graduating valve due to fitting problem between triple valve main piston and graduating valve. Triple valve main piston and graduating valves are connected to each other by pin connection. [20] P_{lgv}=pressure loss amount due to graduating valve leakage.

Table 9 air pressure loss amount due to graduating valve leakage

Assumption % of leakage during graduating valve	P_{lgv} =%l leakage*600KPa= air to pressure loss amount due graduating valve
0.1	0.6
1	6
5	30
10	60

3.4Auxiliary air pressure loss due to triple valve leakage

Since auxiliary reservoirs are located on each car and connected to the brake pipe via triple valve. These reservoir supply the air needed to apply car brakes, when the brake pipe pressure is decreased. [10], [12] Auxiliary reservoir air pressure is an air pressure which is equal to pressure reduction in brake pipe. 600kpa pressure is reduced in brake pipe during braking application. [7]

Due to malfunction of triple valve components auxiliary air pressure is decreased. Auxiliary reservoir is charged due to releasing application. Due to air leaks through triple valve piston head, piston rod, sliding valve and graduating valve auxiliary air pressure is decreased from normal auxiliary air pressure. Normal auxiliary air pressure is 600kpa [7] [1]. Then auxiliary reservoir air pressure due to leakages is equal to the following equation.

$Paux$ = air pressure from auxiliary reservoir

Air pressure from auxiliary reservoir during maximum leakages through triple valve is calculated with the following equation.

$$Paux = 600KPA - Plphmax - Plprmax - Plsvmax - Plgvmax \ldots \ldots \ldots \ldots \ldots 3.11$$

P_{lphmax}= Maximum air pressure leakage through triple valve piston head due to seal wearing

P_{lsvmax}=Maximum air pressure leakage through sliding valve of triple valve

$Plgvmax$ = Maximum air pressure leakage through graduating valve of triple valve

P_{lprmax} = Maximum air pressure leakage through triple valve piston rod due to seal wearing

paux = Auxiliary reservoir air pressure

$Paux$=600kpa- 253.8Kpa-44.19-90Kpa-60Kpa =152.2KPa

Air pressure from auxiliary reservoir during minimum leakages through triple valve is calculated with the following equation.

$$Paux = 600KPA - Plphmin - Plprmin - Plsvmin - Plgvmin \ldots \ldots \ldots \ldots \ldots 3.12$$

Figure 10 and figure 11 shows air leakages through triple valve components during defect.

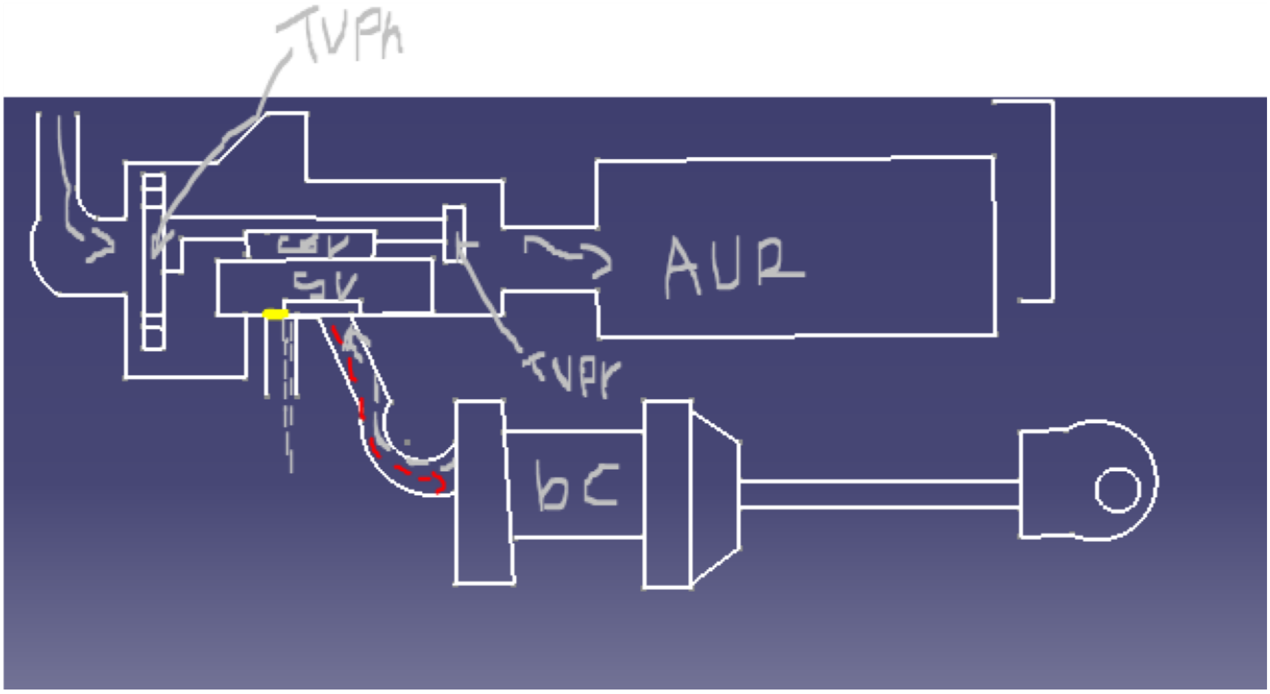

Figure 10 triple valve in release state in addition with braking state

Yellow color shows when sliding valve exhaust port is not fully open, red color shows small amount of air entered to brake cylinder and silver dotted color shows air releasing to atmosphere.

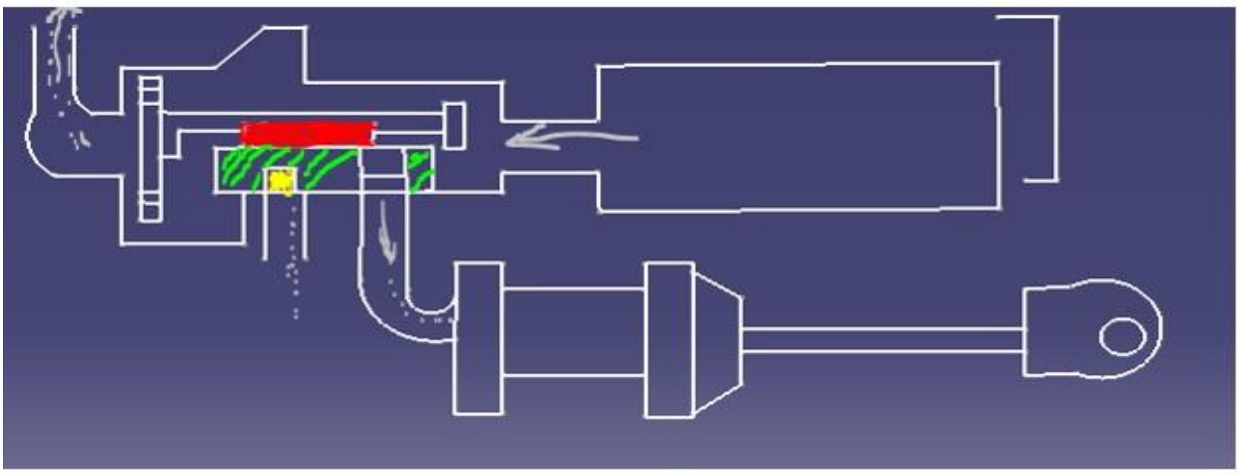

Figure 11 air losses through triple valve during braking state

From above figure the silver color shows air leaks to atmosphere when sliding valve exhaust port is not fully closed. Red color shows graduating valve and green color shows sliding valve.

3.5 Braking time& Braking distance calculation

3.5.1 Braking time

The time taken from the point at which fully developed braking is reached to the time at which the vehicle stops or brake release begins , braking time is gotten by interrelating the following equations:-

$$a = \frac{d_v}{d_t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.13$$

a = acceleration of vehicle

v = velocity of vehicle

t = time

Integrating velocity of vehicle per acceleration vehicle is used to calculate the braking time of the vehicle.

$$\int d_t = \int \frac{d_v}{a} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.14$$

Braking time is equal to mass of vehicle multiplying by initial velocity of vehicle per some of all forces that contribute to the overall braking effort.

$$t_b = \frac{M_{VO}}{T} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.15$$

M = mass of vehicle

vo = initial velocity of vehicle

T= sum of all forces that contribute to the overall braking effort.

t_b= braking time

3.5.2 Frontal and rear axle braking force

F_b= braking force which is equal to the summation of frontal and rear axle

T_f = front axle braking force

Frontal axle has two axles with four disc and pad. Then 8braking force applied on this frontal axle.

T = rear axle braking force

As that of frontal axle, rear axle has two axles with four disc and pad and eight braking force applied on this axle. Totally sixteen (16) times braking force applied on both frontal and rear axles.

3.5.3 Drag force

Since the locomotive moves along straight track, frontal restriction force created by drag force. This drag force is calculated by the following equation:-

$$D = \frac{1\rho C_d A V^2}{2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.16$$

D=Drag force, A= Frontal area of vehicle, V = Vehicle velocity

A = 10m^2 [21]

Vehicle velocity is decreased during braking .Assume average velocity is taken for drag force calculation. Then $V = \frac{16.7m}{s}$

$\rho = air\ density$

$\rho = \frac{1.2K_g}{m^3}$

C_d =drag coefficient

The drag coefficient is a geometrical property of the vehicle body design and it varies

In a range of 0.3 to 0.52 for passenger cars and 0.5 to 1 for heavy duty vehicles such as container carriers and truck [21]

Assume C_d = 0.45

$$D = \frac{1\rho C_d A V^2}{2} = \frac{1.2*0.45*10*16.7^2}{2} = 0.75KN$$

3.5.4 Sum of all forces that contribute to the effort overall braking

Those all forces that contribute to the overall braking efforts are:-

- Drag forces(D)
- Frontal axle forces(Tf)and
- Rear axle forces (Tr)

$$T = T_f + T_r + D + P_{\sin\theta} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . .3.17$$

Assume locomotives moves along the straight track then $P \sin\theta$ =0.

The above equation become as follows

$$T = T_f + T_r + D \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .3.18$$

During service brake application the velocity of vehicle decreases gradually and at last final velocity of vehicle become zero. (i.e. V_f=0), V_f =final velocity during braking

3.5.5 Braking distance

The distance travelled by a vehicle when braking, either during a stop or when the final velocity is non-zero is a basic measure of the effectiveness of a brake system.

A straight forward kinematic analysis assuming straight line (one-dimensional) motion and constant deceleration provides a ready indication of stopping distance. [20]

$$V = \frac{d_x}{d_t} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.19$$

V =vehicle forward speed

$$\frac{T}{M}\int_{X_O}^{X_f} d_x = -\int_{v_o}^{v_f} v_{dv} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.20$$

$$\frac{T}{M}\left(X_{f_{X_o}}\right) = \frac{T_x}{M} = V_O^2 - V_f^2 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad 3.21$$

$$X = \frac{M_{VO^2}}{2T} \dots\dots\dots 3.22$$

x = Stopping distance

3.5.6 Leakages through triple valve for analyzing to be considered are:-

- Minimum and maximum leakages through triple valve piston head(TVPh),triple valve piston rod(TVPr), sliding valve (SV), graduating valve(GV)
- Minimum and maximum leakages through sliding valve (SV) & graduating valve(GV)
- Minimum and maximum leakages through triple valve piston head(TVPh) & triple valve piston rod (TVPr)
- Minimum and maximum leakages through triple valve piston head (TVPh),triple valve piston rod(TVPr) & sliding valve
- Minimum and maximum leakages through triple valve piston head(TVPh) & sliding valve(SV)
- Braking force during maximum and minimum leakages through triple valve piston head, triple valve piston rod, sliding valve and graduating valve.

During braking application the force created by pressure loss is subtracted from normal braking force (i.e. From force created without leakage). Those losses are created on triple valve piston head, piston rod, sliding valve and graduating valve.

3.5.7 Braking force

Braking force which is used to stop locomotive is equal to sum of all forces that contribute to the overall braking effort (T) .Then Fb = T

F_b=braking force

Sum of all forces that contribute to the overall braking effort (T) during maximum leakages through triple valve piston head, triple valve piston rod, sliding valve and graduating valve are written with an equation of 3.18.

Then $F_b = T = T_f + T_r + D$

Braking force created on frontal and rare axle is equal to auxiliary air pressure times braking cylinder piston area.

$F = P * A$ … 3.23

F = force

P=pressure

A =area

According to above equation braking force created on frontal and rare axle is written as follow

$F_b = P_{aux} * A_{bcp}$ ….. 3.24

Four axle locomotive with two bogie produces $16F_b$. Then equation 3.24 is written as follow:-

$F_b = 16 * (P_{aux} * A_{bcp})$ … .3.25

During leakages through triple valve main components auxiliary air pressure is decreased. Air pressure reduction through train pipe is equal to auxiliary air pressure. [7]. but during leakages P_{aux} becomes as follow:-

$P_{aux} = P - \text{Leakages}$ … 3.26

P= standard air pressure reduction from train pipe which is equal to 600KPa

Those leakages are occurs through triple valve piston head, triple valve piston rod, sliding valve and graduating valve.

Maximum & and minimum pressure losses through triple valve piston head, piston rod, sliding valve and graduating valve is shown with the following graph

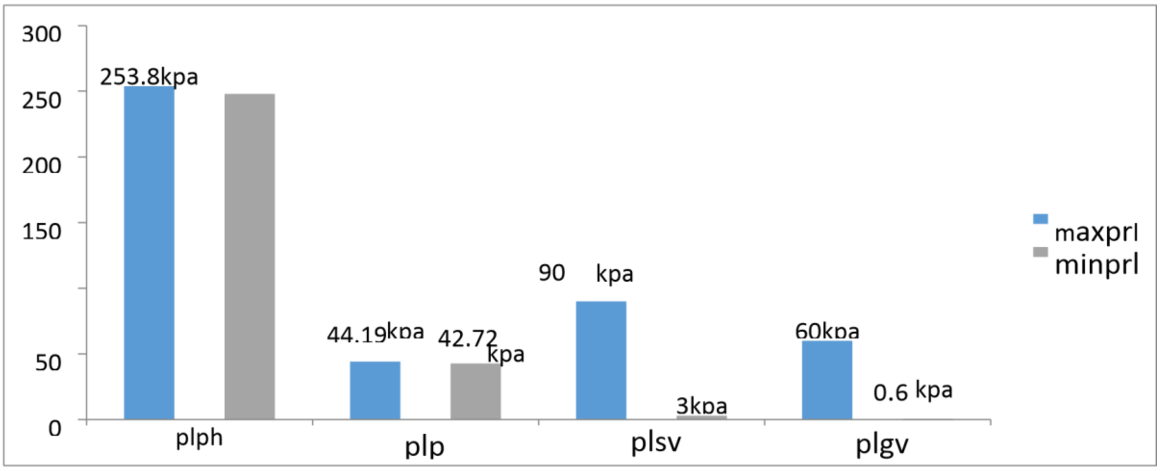

Figure 12 maximum and minimum air pressure losses through main parts of triple valve

Maxprl= maximum pressure loss, minprl = minimum pressure loss

The above chart shows the maximum and minimum pressure loss through triple valve parts such as triple valve piston head, triple valve piston rod, sliding valve and graduating valve.

Then braking force during leakages through triple valve main parts at different rates are written with the following equation

$F_b = 16[(P - P_{lph} - P_{lpr} - P_{lsv} - P_{lgv}) * A_{bcp} * 0.95] + D$ … … … … … … … … ………..3.27

P= standard air pressure reduction from train pipe

P_{lph}=pressure loss through triple valve piston head due to seal worn

P_{lpr} = pressure loss through triple valve piston rod due to seal worn

P_{lsv}=pressure losses through sliding valve

P_{lgv}= pressure losses through graduating valve

A_{bcp}=area of brake cylinder piston which is equal to $0.10463m^2$ [10]

Assumption for rigging effect is 0.95

Braking force calculation is done with maximum and minimum leakages through triple valve main components.

Sum of all forces that contribute to the overall braking effort (T) due to maximum pressure losses through triple valve piston head, piston rod, sliding valve& graduating valve.

$$F_b = 16[(P - P_{lph} - P_{lpr} - P_{lsv} - P_{lgv}) * A_{bcp} * 0.95] + D$$

$$F_b = 16[(600 - 253.8 - 44.19 - 90 - 60) * 0.10463 * 0.95] + 0.75 = 610.55K_N$$

Sum of all forces that contribute to the overall braking effort (T) due to minimum pressure losses through triple valve piston head, piston rod, sliding valve& graduating valve is calculated with the same equation as maximum leakage .

$$F_b = 16[(P - P_{lph} - P_{lpr} - P_{lsv} - P_{lgv}) * A_{bcp} * 0.95] + D$$

$$F_b = 16[(600 - 247.9 - 42.72 - 3 - 0.6) * 0.10463 * 0.95] + 0.75 = 841.3KN$$

3.5.8 Braking time

Braking time due to Maximum pressure losses through triple valve piston head, piston rod, sliding valve& graduating valve is calculated with an equation 3.15.

$$t_b = \frac{M_{vo}}{T} = \frac{M_{vo}}{16[(P - P_{lph} - P_{lpr} - P_{lsv} - P_{lgv}) * A_{bcp} * 0.95] + D}$$

$$t_b = \frac{M_{vo}}{T} = \frac{150000K_g * 33.33\frac{m}{s}}{610.55K} = 8.1se$$

During minimum leakages through those components braking time becomes as follow

$$t_b = \frac{M_{vo}}{T} = \frac{150000*33.33}{841.3*1000} = 5.94Se$$

3.5.9 Braking distance

Braking distance due to Maximum pressure losses through triple valve piston head, piston rod, sliding valve& graduating valve is calculated with an equation of 3.22

$$X = \frac{M_{VO^2}}{2T} = \frac{M_{VO^2}}{2(16[(P - P_{lph} - P_{lpr} - P_{lsv} - P_{lgv}) * A_{bcp} * 0.95] + D}$$

$$X = s_b = \frac{M_{VO^2}}{2T} = \frac{150000*33.33^2}{2(610.55*1000)} = 136.5m$$

Braking force calculation during Minimum pressure losses through triple valve piston head, piston rod, sliding valve& graduating valve is written as follow

$$s_b = \frac{M_{VO^2}}{2T} = \frac{150000*33.33^2}{2(841.3*1000)} = 99m$$

Table 10 maximum leakages through TVPh, TVPr & SV

leakage through	Max.leakage(Kpa)	$F_b = 16[(P - P_{lph}\text{-}P_{lpr} - S_V)*A_{bcp}*0.95] + D$	$t_b = \frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
TVPh	253.8	705.221KN	7.1 Se	118.1m
TVPr	44.19	705.221KN		
SV	90	705.221KN		

Table 11 minimum leakages through TVPh, TVPr & SV

leakage through	min.leakage(Kpa)	$F_b = 16[(P - P_{lph}\text{-}P_{lpr} - S_V)*A_{bcp}*0.95] + D$	$t_b = \frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
TVPh	247.9	842.089KN	5.94 Se	98m
TVPr	42.72	842.089KN		
SV	3	842.089KN		

Table 12 Maximum leakages through TVPh, TVPr

leakage through	max.leakage(Kpa)	$F_b = 16[(P - P_{lph}\text{-}P_{lpr})*A_{bcp}*0.95] + D$	$t_b = \frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
TVPh	253.8	846.8KN	5.89 Se	98.2m
TVPr	44.19	846.8KN		

Table 13 Minimum leakages through TVPh, TVPr

leakage through	min.leakage(Kpa)	$F_b = 16[(P - P_{lph}\text{-}P_{lpr})*A_{bcp}*0.95] + D$	$t_b = \frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
TVPh	247.9	846.9KN	5.90 Se	98.4m
TVPr	42.72	846.9KN		

Table 14 Maximum leakages through SV, GV

leakage through	max.leakage(Kpa)	$F_b = 16[(P - P_{lsv}\text{-}P_{lgv})*A_{bcp}*0.95] + D$	$t_b = \frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
SV	90	716.42KN	6.98Se	116.3m
GV	60	716.42KN		

Table 15 Minimum leakages through SV, GV

leakage through	min.leakage(Kpa)	$F_b = 16[(P - P_{lsv}-P_{lgv})*A_{bcp}*0.95]$ +D	$t_b=\frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
SV	3	949.3KN	5.26Se	87.76m
GV	0.6	948.3KN		

Table 16 Maximum leakages through TVPh, SV

leakage through	max.leakage(Kpa)	$F_b = 16[(P - P_{lsv}-P_{lgv})*A_{bcp}*0.95]$ +D	$t_b=\frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
TVPh	253.8	771.5KN	6.5se	108m
SV	90	771.5KN		

Table 17 Minimum leakages through SV, GV

leakage through	min.leakage(Kpa)	$F_b = 16[(P - P_{lsv}-P_{lgv})*A_{bcp}*0.95]$ +D	$t_b=\frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
TVPh	247.9	910.02KN	5.5 Se	91.6m
SV	3	910.02KN		

Table 18 No leakages through TVPh, TVPr, and SV& GV

no leakage through TV	Leakage(Kpa)	$F_b = 16[(P*A_{bcp}*0.95)]$ +D	$t_b=\frac{M_{vo}}{T}$	$S_b = \frac{M_{vo}^2}{2T}$
TVPh	0	954.32KN	5.23Se	87.3m
TVPr	0	954.32KN		
SV	0	954.32KN		
GV	0	954.32KN		

Table 19 Parameters and variables used in the simulation model

Standard air pressure reduced through pipe (P)	600KPa
Minimum air pressure leakage through sliding valve	3KPa
Minimum air pressure leakage through sliding valve	0.6 KPa
The depth (thickness) of seal (tsd)	22mm

triple valve piston head diameter	0.040m
triple valve piston rod diameter	0.080m
Triple valve piston maximum movement	0.023m
Mass factor	1.05
Coefficient of drag(Cd)	0.45
Initial velocity(Vo)	$120\frac{km}{hr}$
Air density	$\rho = \frac{1.2kg}{m^3}$
Mass of vehicle (M)	150000 Kg

[9],[12],[17],[18]

CHAPTER 4

4 Modeling block diagram at different leakage rates through triple valve

Block diagrams are modeled during minimum and maximum leakage rates.

Those leakages are leakages through:-

- Leakages through TVPh, TVPr, SV &GV
- Leakages through TVPh, TVPr & SV
- Leakages through TVPh & TVPr &
- Leakages through SV& GV

4.1 Block diagram for maximum leakages through TVPh,TVPr,SV& GV

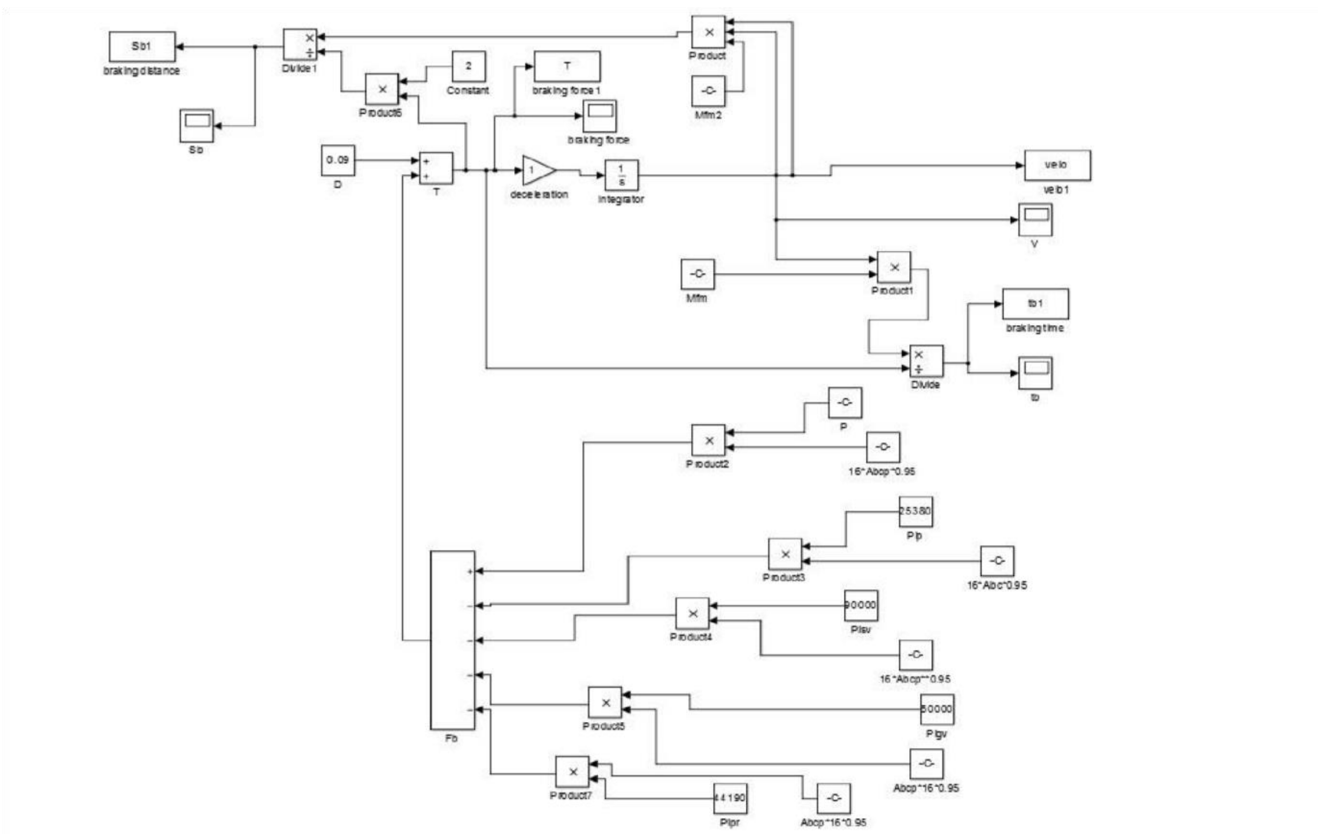

Figure 13 Block diagram for maximum   leakages through TVPh,TVPr,SV&GV

During maximum leakages through TVPh, TVPr,SV& GV maximum amount of air losses are fed into Simulink mat lab modeling. Those values which are fed into Simulink matlab are taken from table 4, table 7, table 8 & table 9

4.2 Block diagram for minimum leakages through TVPh,TVPr,SV& GV

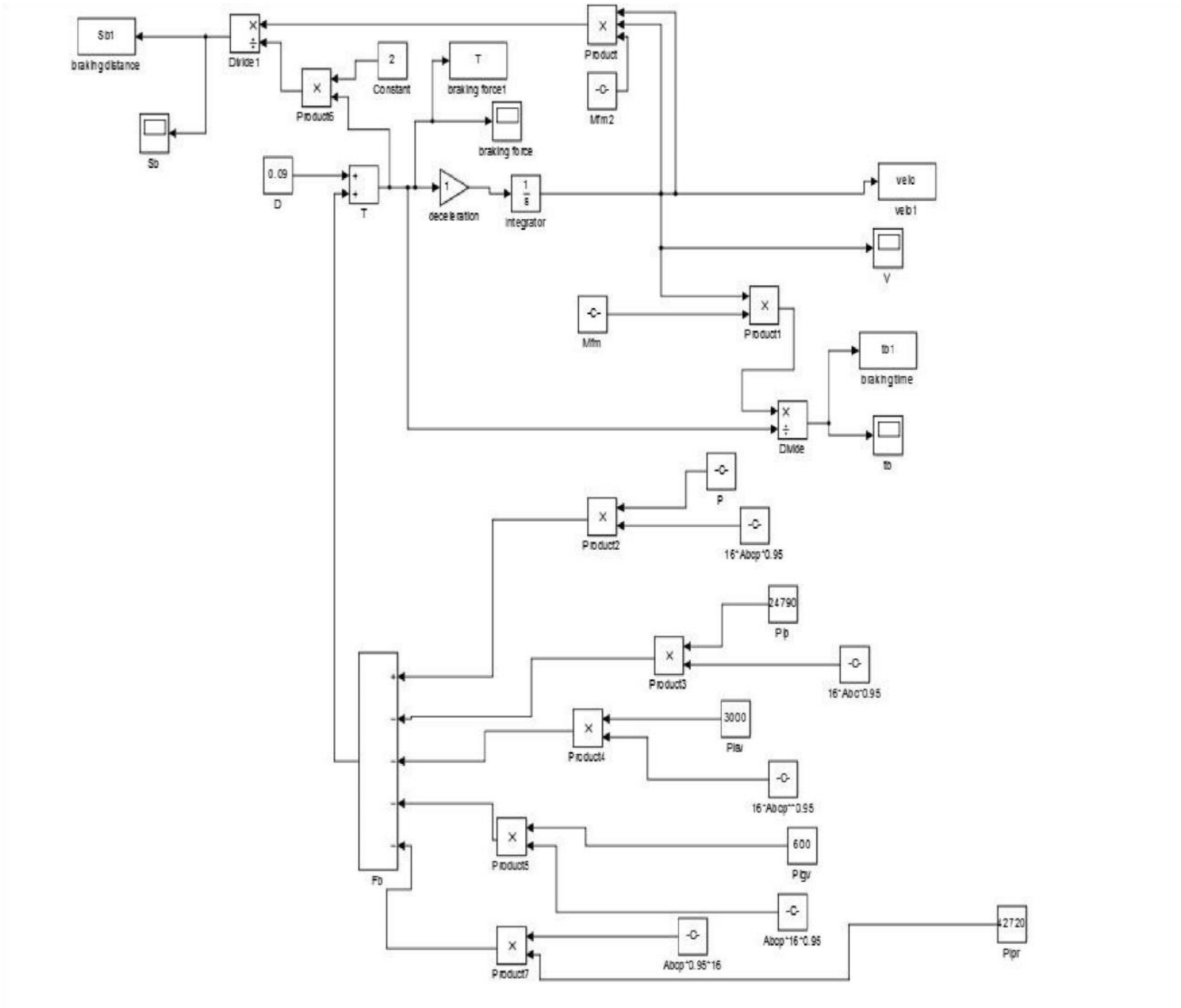

Figure 14 Block diagram for minimum leakages through TVPh,TVPr,SV&GV

For minimum leakages through TVPh, TVPr,SV& GV minimum amount of air losses are fed into Simulink mat lab modeling. Those values which are fed into Simulink matlab are taken from table 4, table 7, table 8 & table 9

4.3 Block diagram for maximum leakages through TVPh,TVPr,SV

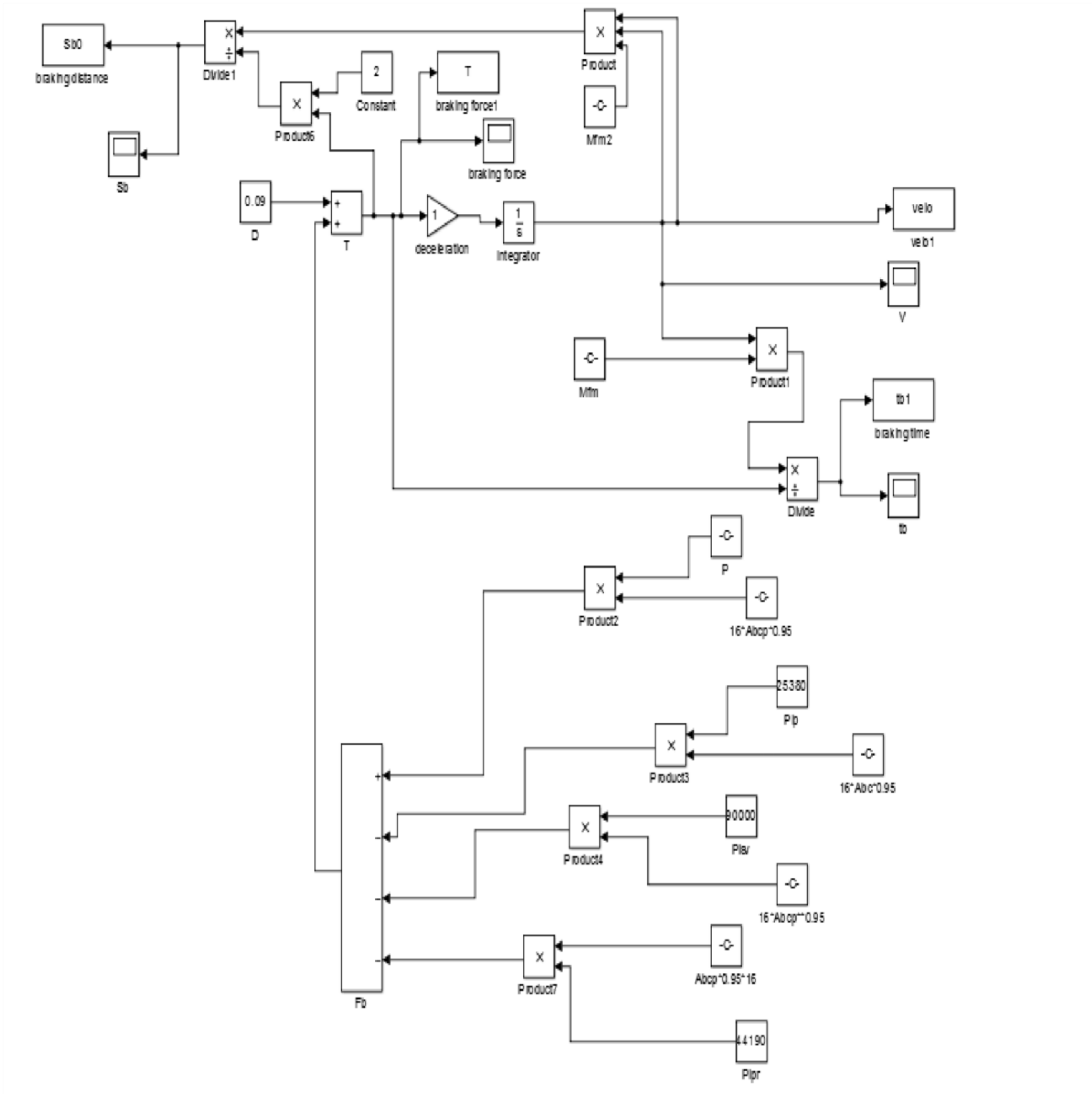

Figure 15 Block diagram for maximum leakages through TVPh,TVPr,SV

From figure 17 leakages through GV is zero but leakages through TVPh, TVPr and SV are maximum. Those values which are fed to Simulink matlab models are taken from table 4, table 7 and table 8.

4.4 Block diagram for minimum leakages through TVPh,TVPr,SV

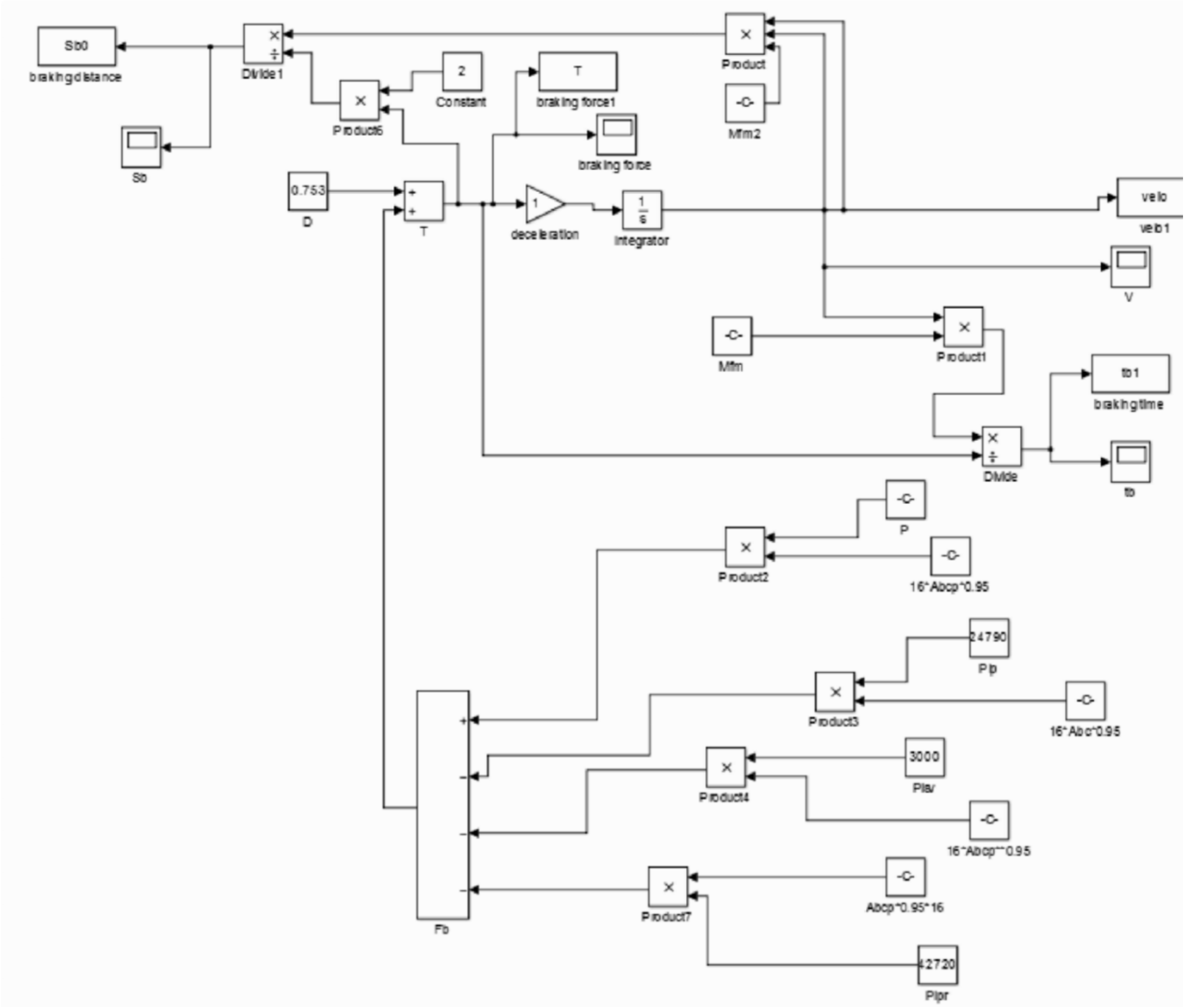

Figure 16 Block diagram for minimum leakages through TVPh,TVPr,SV

Minimum amount of leakages are fed into above block diagram from table 4, table7 & table 8. Also leakages through GV are zero as maximum leakages expressed above.

4.5 Block diagram for maximum leakages through SV & GV

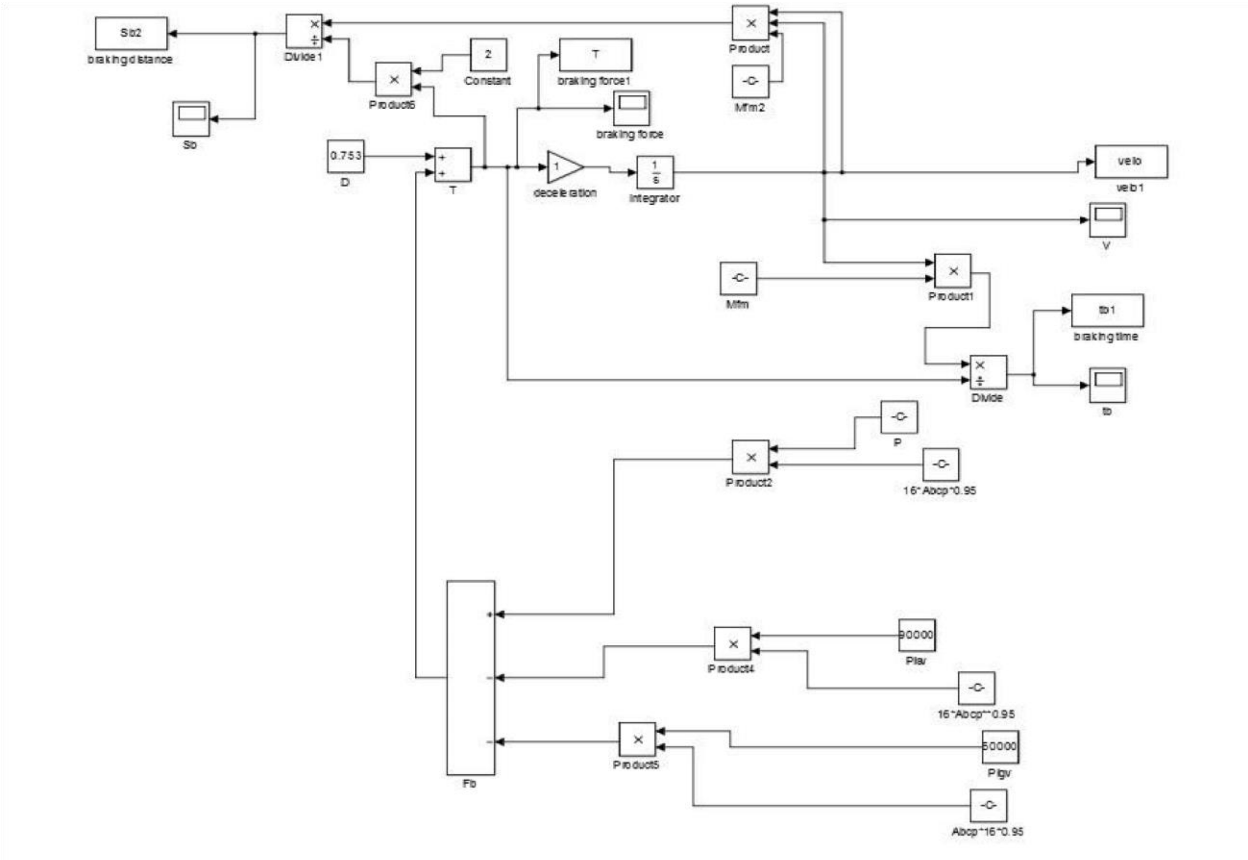

Figure 17 Block diagram for maximum leakages through SV&GV

During this leakages maximum amount of leakages are fed into Simulink mat lab of modeled block diagram. When leakages occurs in both SV & GV other components such as TVPh and

TVPr have no leakages so leakages through both TVPh and TVPr are assumed to be zero. Maximum amount of leakages are fed in this cases are taken from table 8 & table 9

4.6 Block diagram for minimum leakages through SV & GV

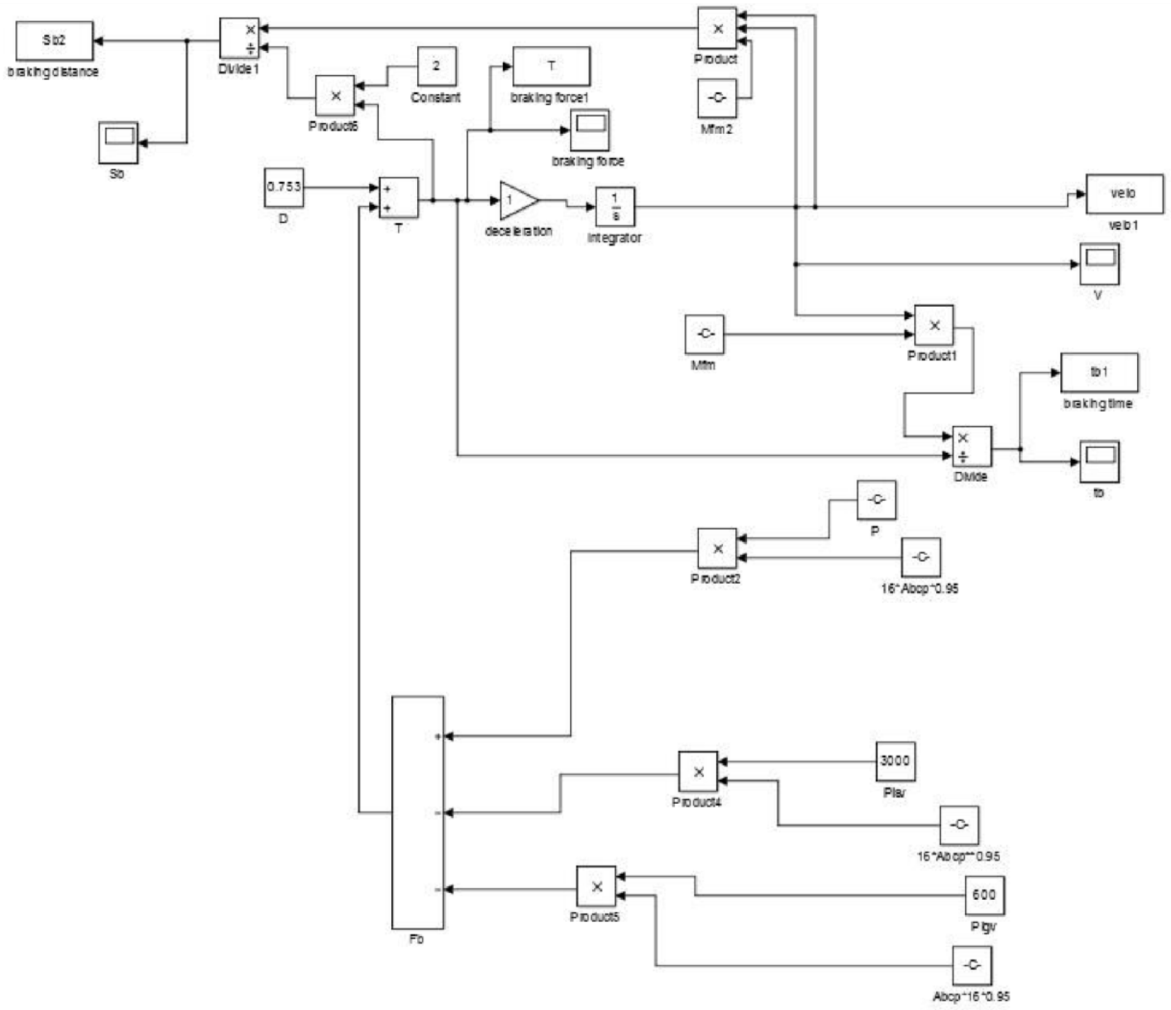

Figure 18 Block diagram for minimum leakages through SV&Gv

For minimum leakages through SV & GV minimum amount of air losses due to both cases are subtracted from standard air pressure reduced from train pipe. But others components assumed to have zero leakages.

4.7 Block diagram for maximum leakages through TVPh & TVPr

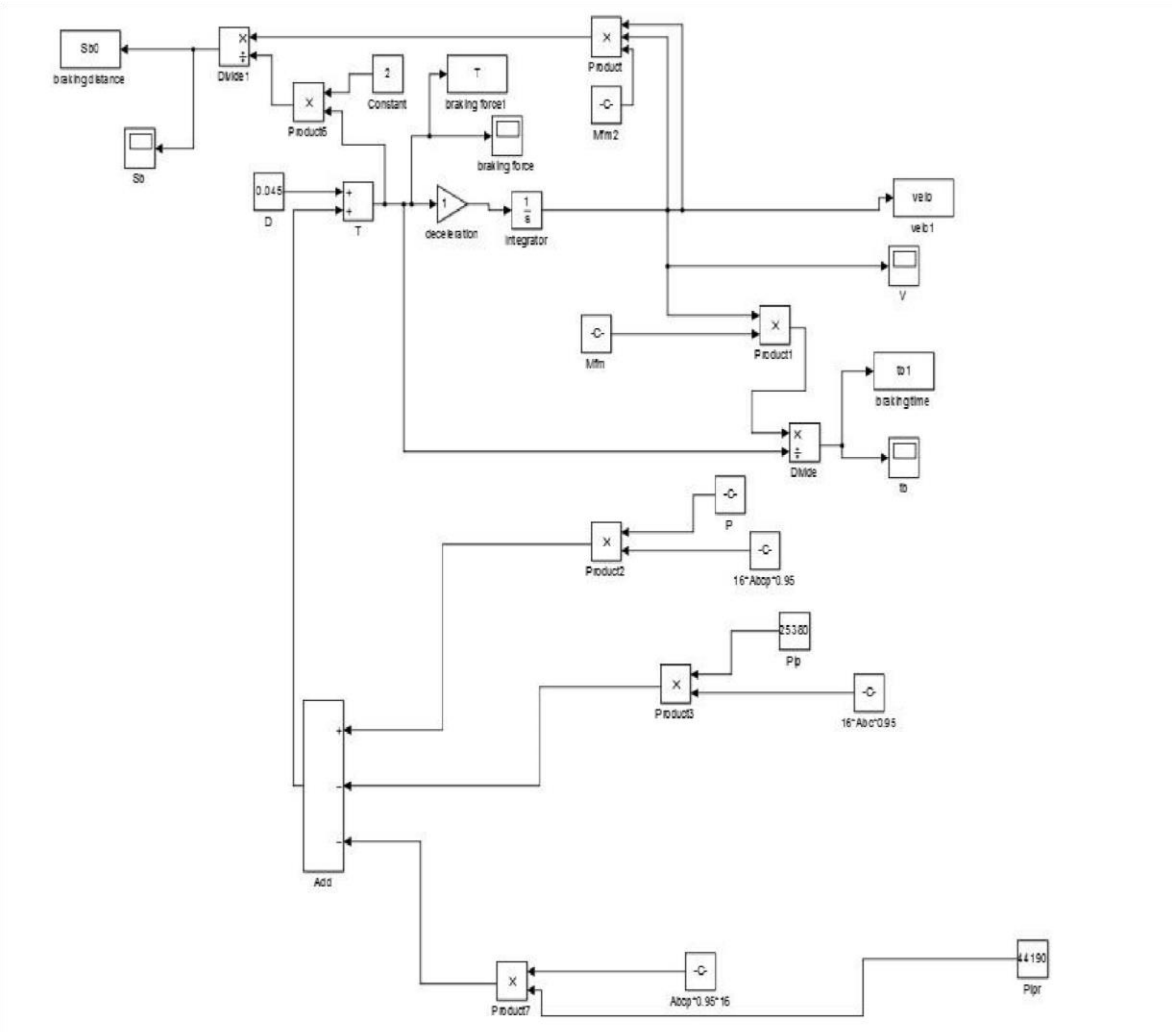

Figure 19 Block diagram for maximum leakages through TVPh &TVPr

Maximum leakages through both TVPh & TVPr are subtracted from standard air pressure reduced from train pipe. But in this cases others are assumed to have no leakages. (i.e. There is no leakage through sliding valve and graduating valve). And subtracted values are fed into Simulink mat lab model from table 4 & from table 7

4.8 Block diagram for minimum leakages through TVPh & TVPr

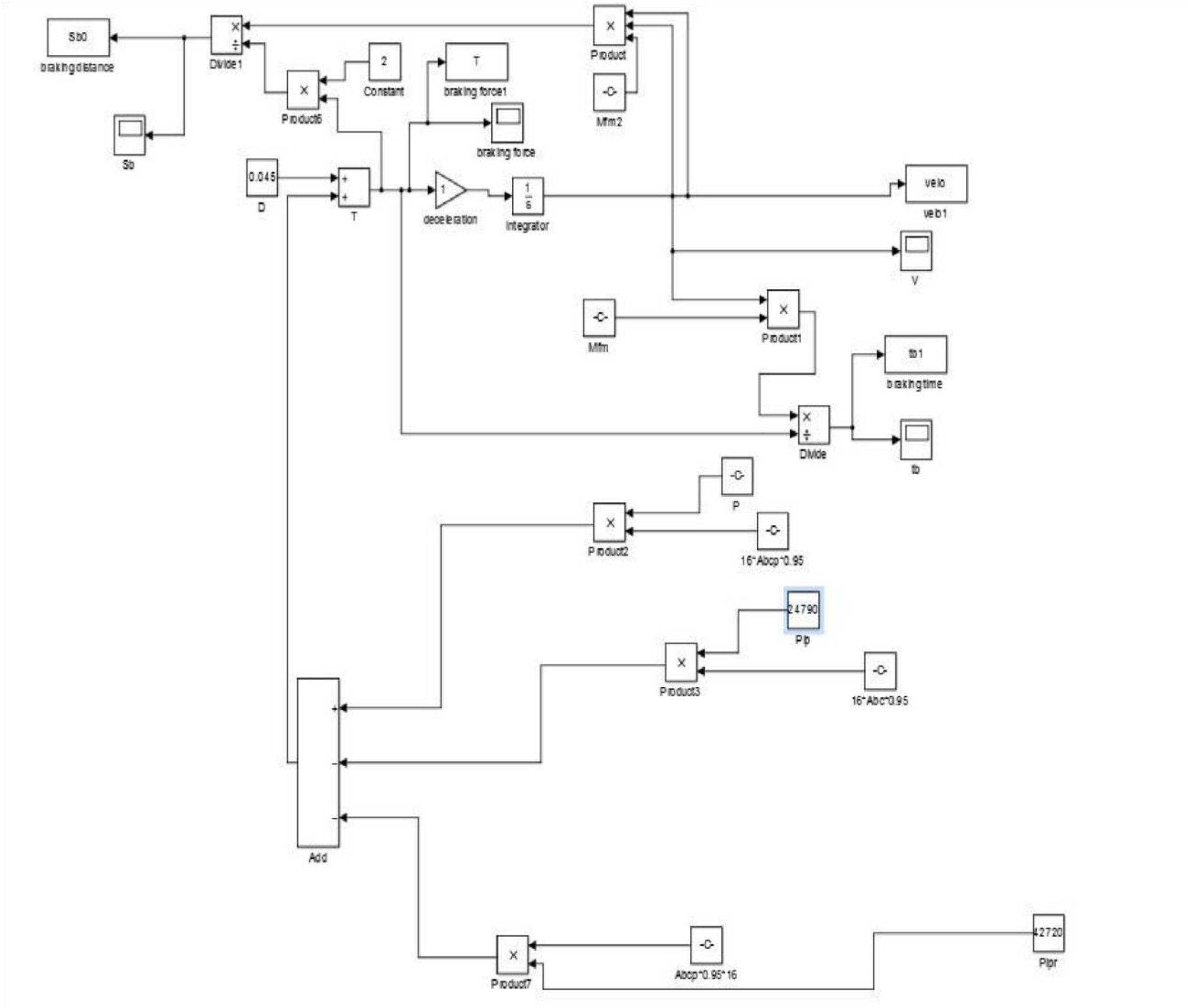

Figure 20 Block diagram for minimum leakages through TVPh &TVPr

During this cases minimum amount of air losses due to TVPh & TVPr malfunction are subtracted from auxiliary air pressure. But other components have zero leakages. Subtracted value are fed into Simulink model from table 4 & table 7

4.9 Block diagram for maximum leakages through TVPh & SV

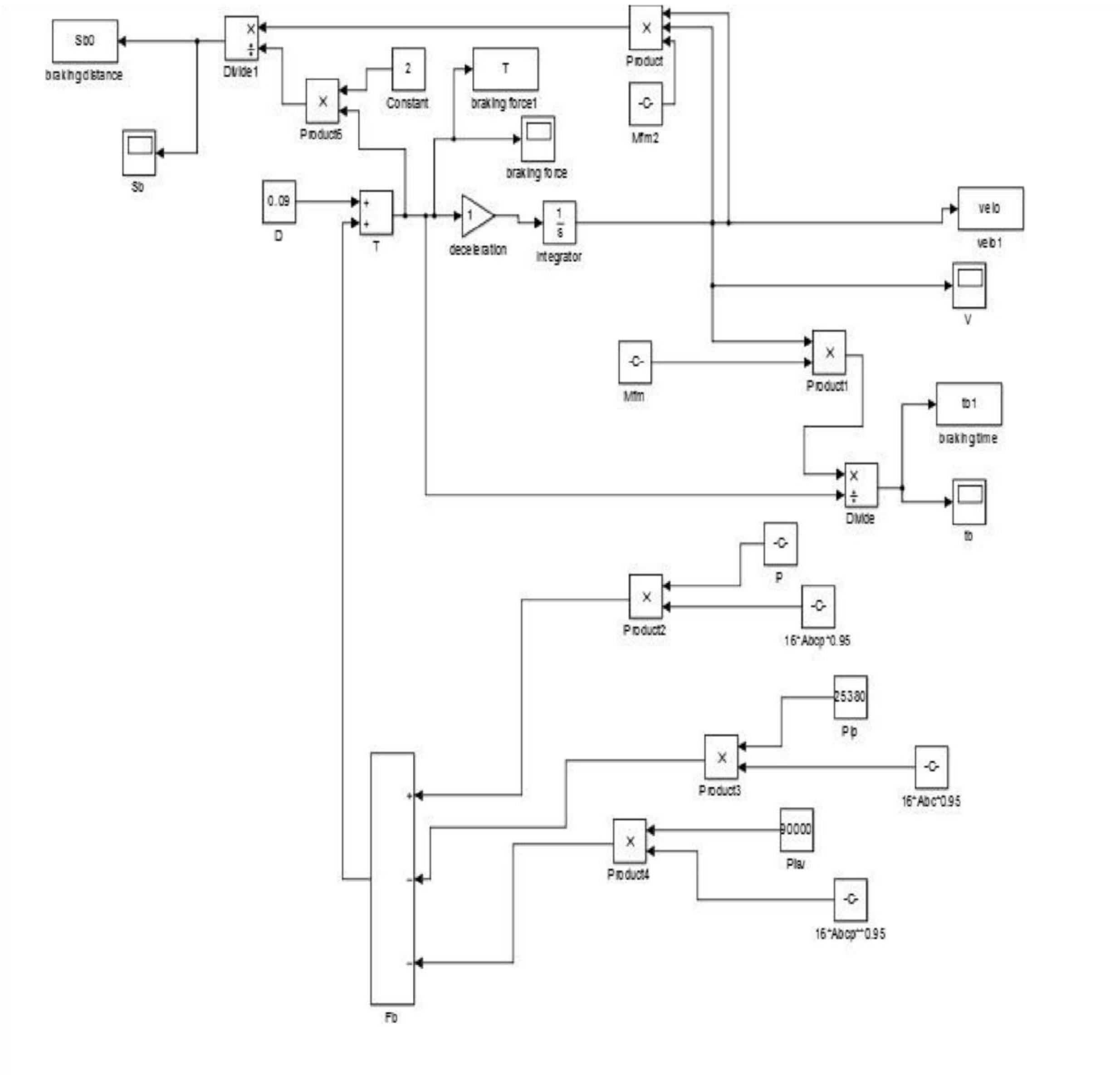

Figure 21 Block diagram for maximum leakages through TVPh & SV

For this cases maximum amount of air leakages due to TVPh & SV malfunction are subtracted from standard air pressure reduced from train pipe. And subtracted values are taken from table 4 and table 8.

4.10 Block diagram for minimum leakages through TVPh & SV

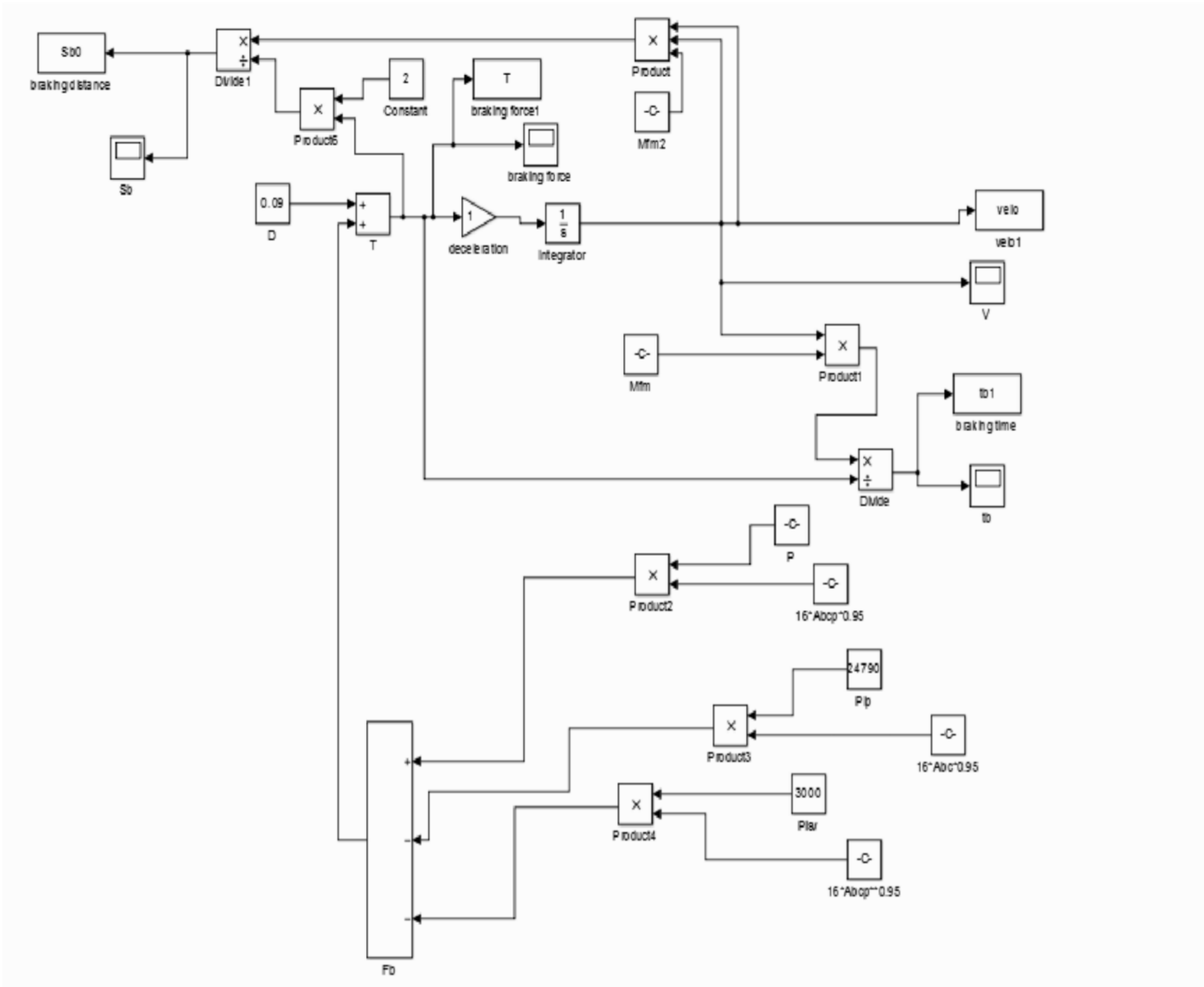

Figure 22 Block diagram for minimum leakages through TVPh & SV

For above diagram minimum amount of air leakages due to TVPh & SV malfunction are subtracted from standard air pressure reduced from train pipe. And subtracted values are taken from table 4 and table 8.

4.11 Block diagram for triple valve with no leakages

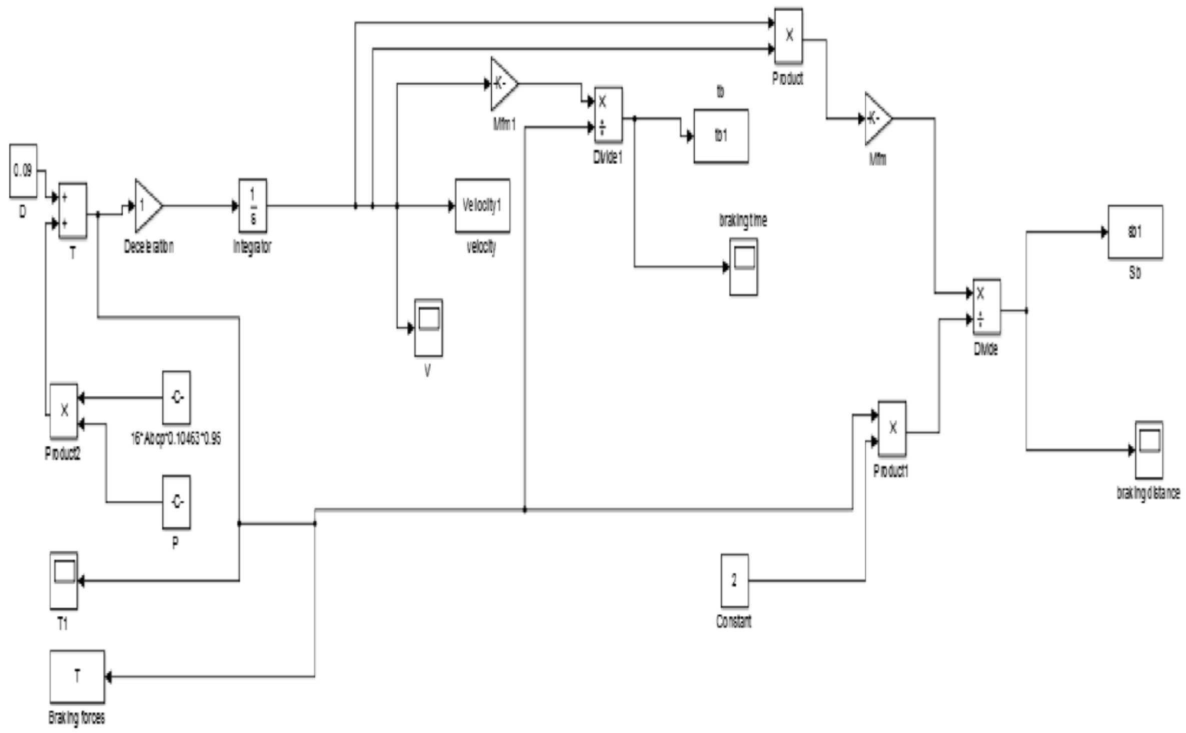

Figure 23 block diagram for triple valve with no leakages

During this cases leakages through TVPh , SV, TVPr and GV are neglected

CHAPTER 5

5 RESULT & DISCUSSION

In this chapter simulation results during maximum and minimum leakages through TVPh, TVPr, and SV & GV are discussed.

5.1 Simulation results on maximum leakages through TVPh, TVPr, SV & GV

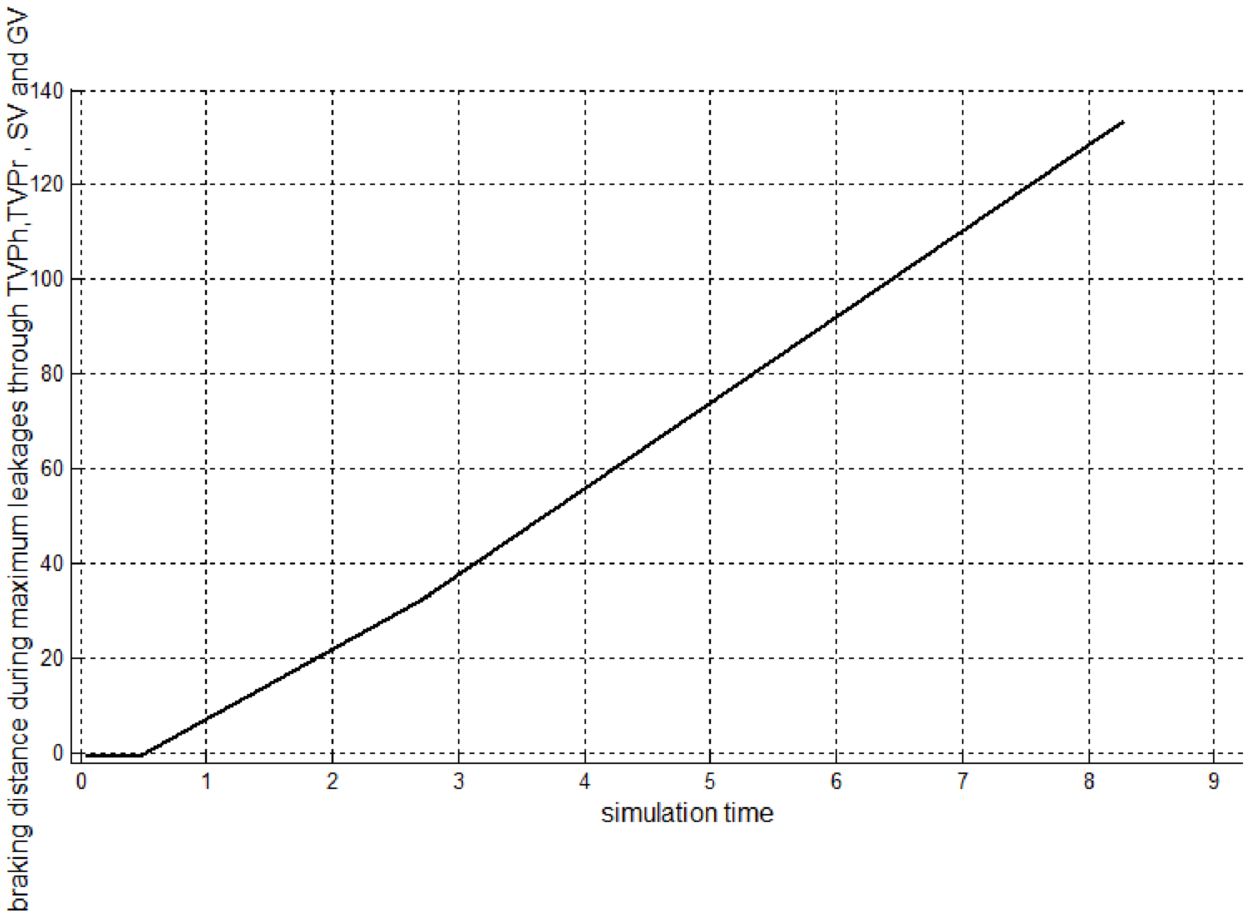

Figure 24 braking distance during maximum leakages through TVPh,TVPr,SV& GV VS simulation time

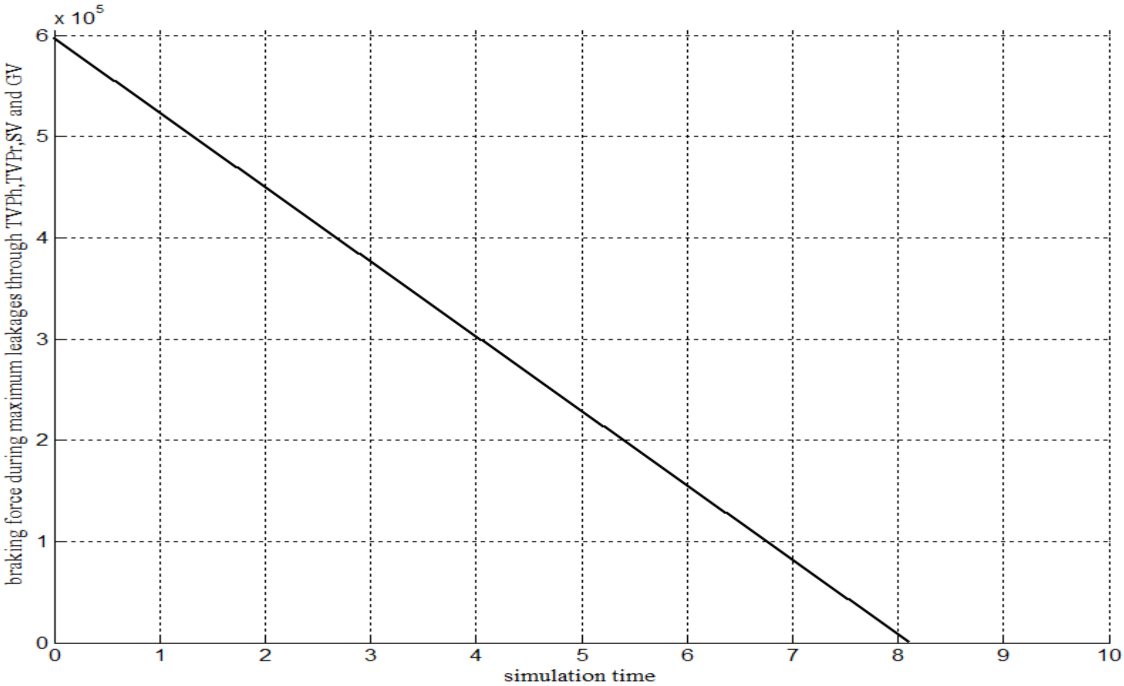

Figure 25 braking force during maximum leakages through TVPh,TVPr,SV& GV VS simulation time

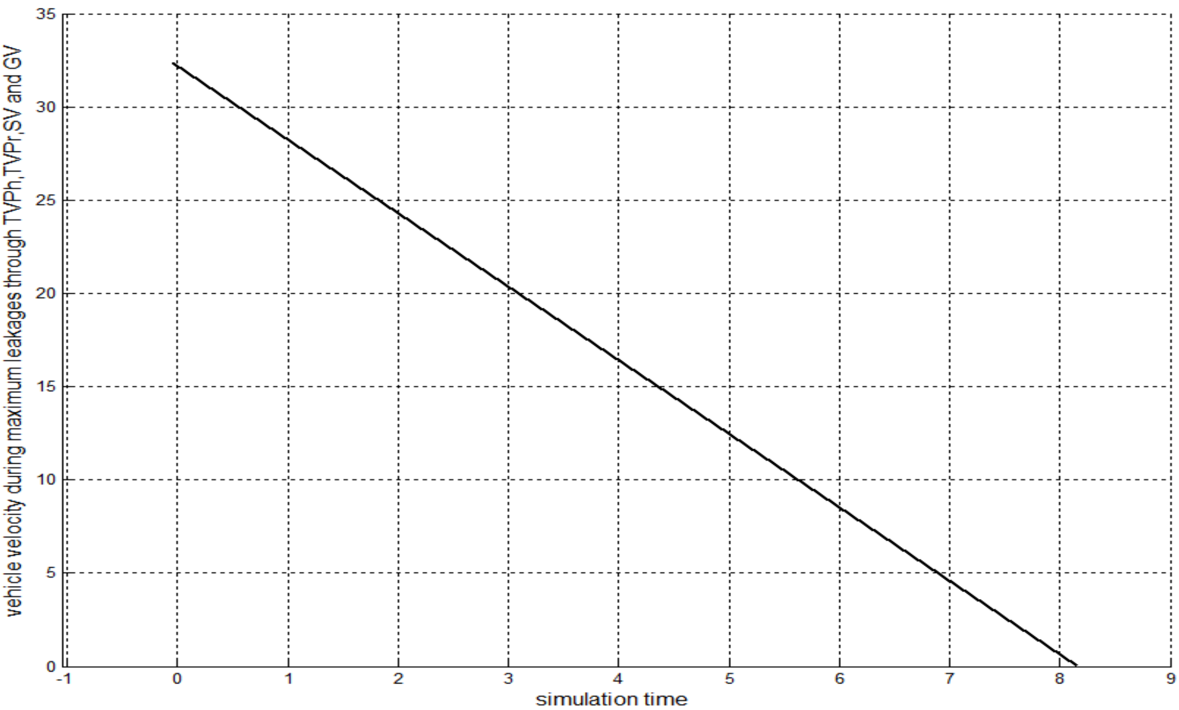

Figure 26 Vehicle velocity during maximum leakages through TVPh,TVPr,SV & GV vs. simulation time

5.2 Discussion on maximum leakages through TVPh, TVPr, SV & GV

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se. simulated result of braking distance during leakage through triple valve piston head, triple valve piston rod, sliding valve, and graduating valve is 136.5m with simulating time of 8se.

From figure 24 braking distance during maximum percentage leakages through TVPh, TVPr, SV& GV is 136.5m at a simulation time of 8.1 sec. Braking distance during this case is greater than braking distance during normal operation of triple valve. Braking distance increases when braking time increases. Braking distance created during zero leakages through triple valve is 87.3m From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during maximum leakages through triple valve piston head, triple valve piston rod, sliding valve and graduating valve case is 8.1sec

From fig 25 vehicle velocity during maximum percentage leakages through TVPh, TVPr, SV& GV is decreased and become zero within 8.1sec of simulation time. When simulation time increases vehicle velocity is decreased.

From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 26 maximum braking force 954230N with simulation time 8.1se. From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances.

From figure 26 braking force during maximum percentage leakages through TVPh, TVPr,SV& GV is 610.55 KN at simulation time of 8.1sec

5.3 Simulation results on minimum leakages through TVPh, TVPr, SV & GV

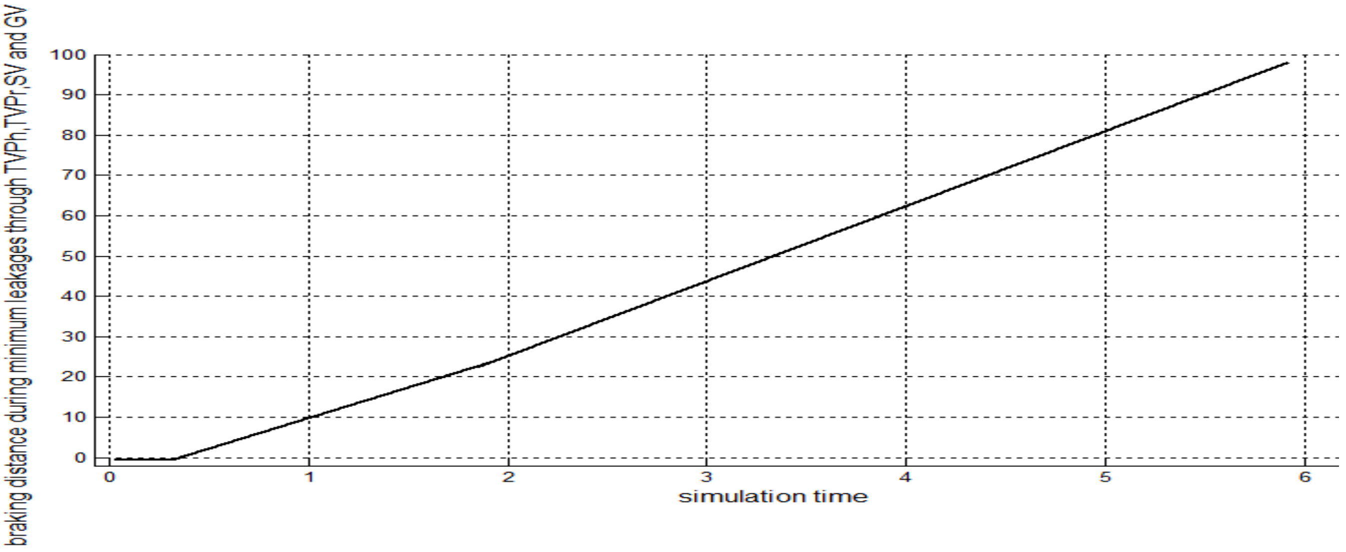

Figure 27 braking distance during minimum leakages through TVPh,TVPr,SV& GV VS simulation time

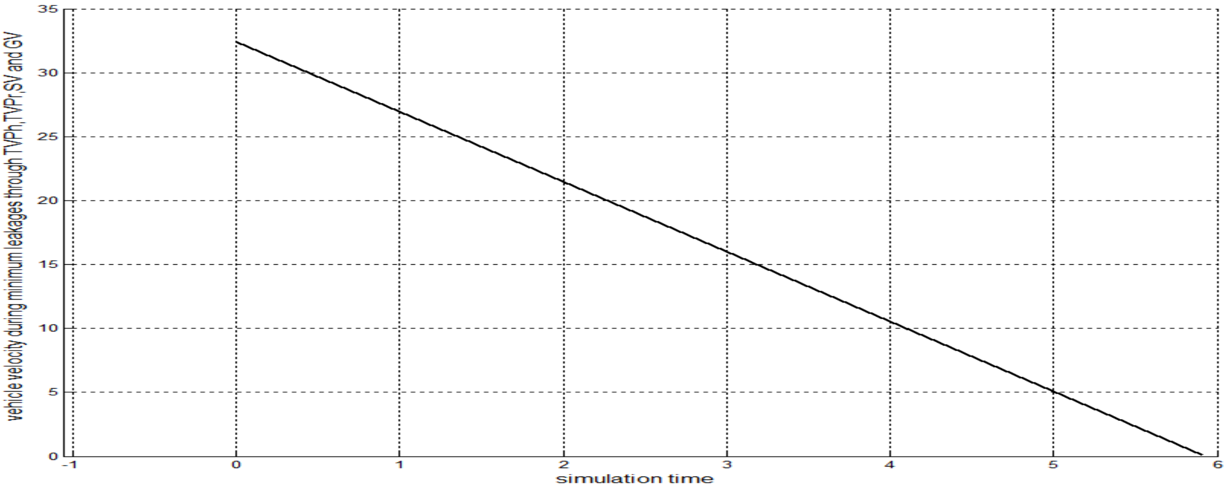

Figure 28 Vehicle velocity during minimum leakages through TVPh,TVPr,SV& GV VS simulation time

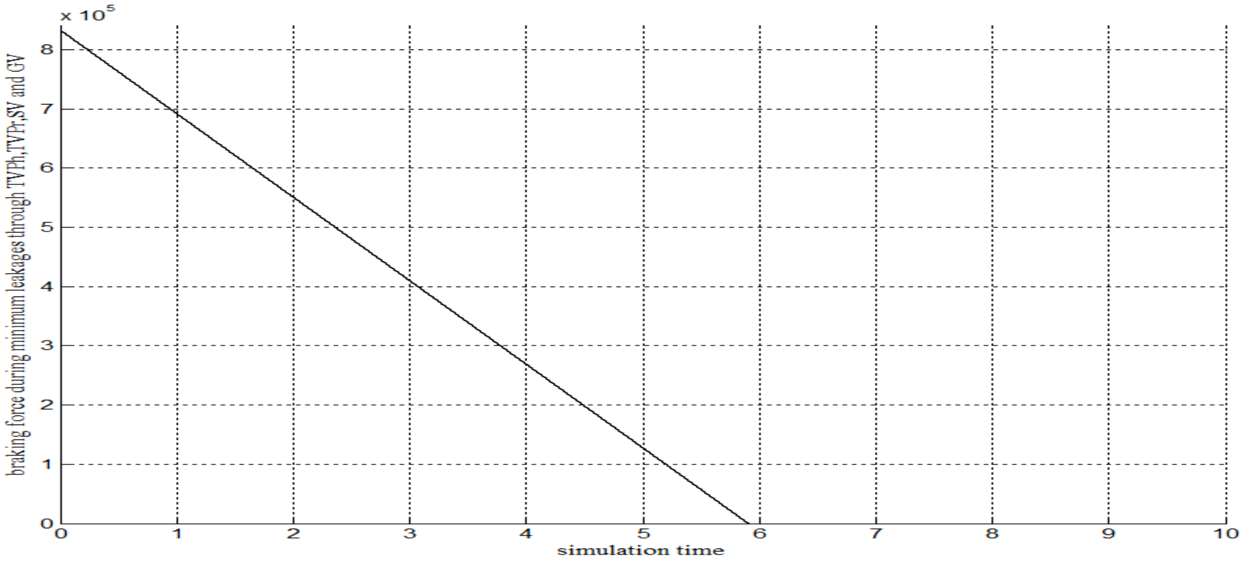

Figure 29 braking force during minimum leakages through TVPh,TVPr,SV& GV VS simulation time

5.4 Discussion on minimum leakages through TVPh, TVPr, SV & GV

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se. From figure 27 simulated result of braking distance during minimum leakage through triple valve piston head, triple valve piston rod, sliding valve, and graduating valve is 99m with simulating time of 5.94se.

Braking distance created during this case is greater than braking distance during normal operation of triple valve. Braking distance increases when simulation time increases.

From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during maximum leakages through triple valve piston head, triple valve piston rod, sliding valve and graduating valve case is 5.94 sec

From figure28 vehicle velocity during minimum percentage leakages through TVPh, TVPr, SV & GV is decreased when simulation time increases and become zero at 5.94sec of simulation time.

From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 29 minimum braking force $8.413 * 10^5 N$ .with simulation time5.94sec. From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances

5.5 Simulation results on maximum leakages through TVPh, TVPr & SV

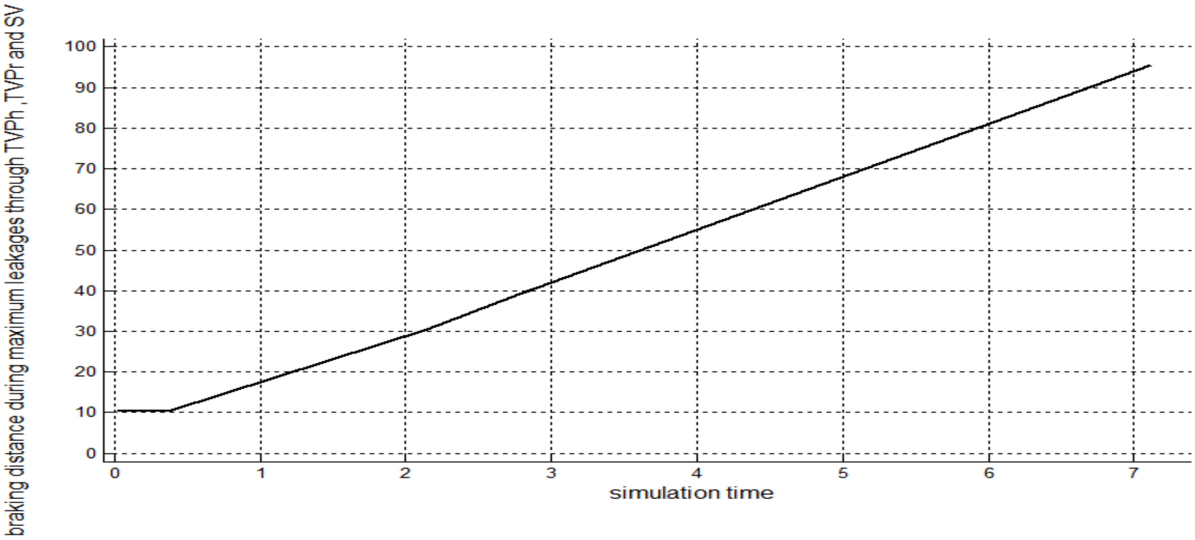

Figure 30 braking distance during maximum leakages through TVPh,TVPr,SV& VS simulation time

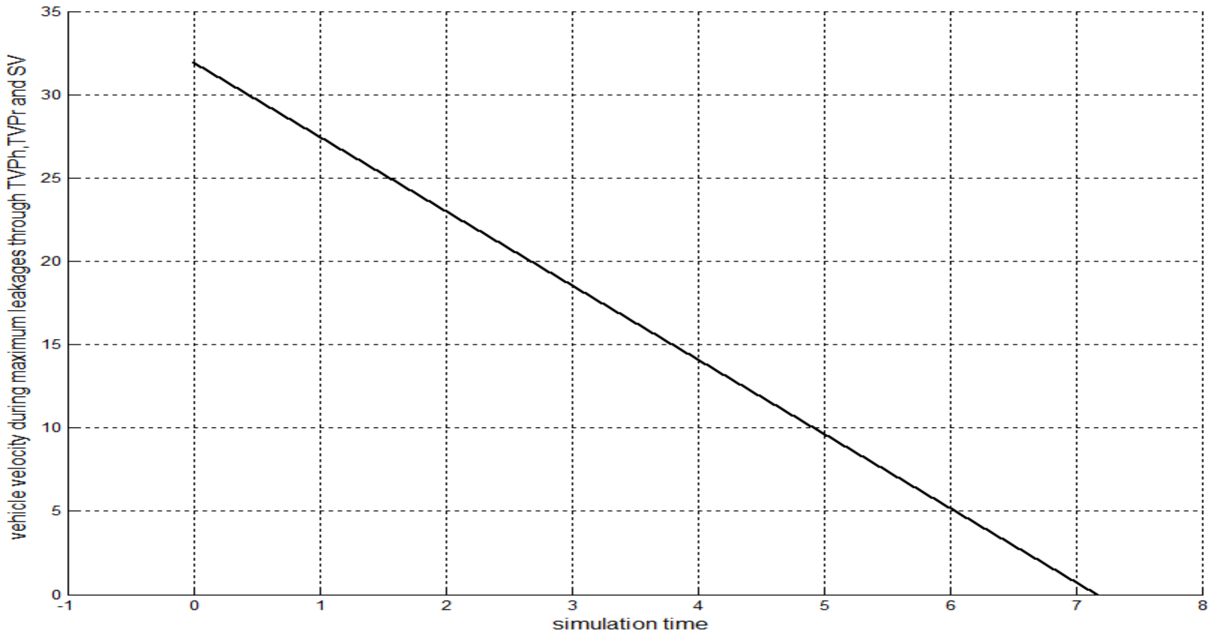

Figure 31 vehicle velocity during maximum leakages through TVPh,TVPr,SV& VS simulation time

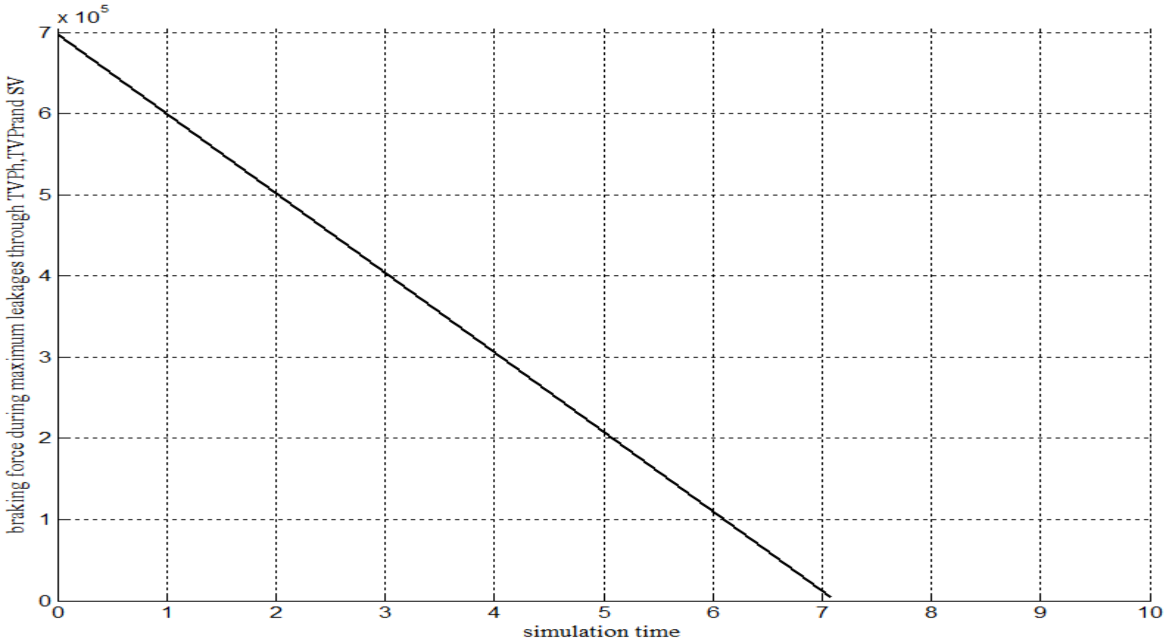

Figure 32 braking force during maximum leakages through TVPh,TVPr,SV& VS simulation time

5.6 Discussion on maximum leakages through TVPh, TVPr, & SV

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se.
From figure 30 braking distance during maximum percentage leakages through TVPh, TVPr, & SV is 118.1m at a simulation time of 7.1 sec.
From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during maximum leakages through triple valve piston head, triple valve piston rod and sliding valve case is 7.1sec
From figure 31 vehicle velocity during maximum percentage leakage through triple valve piston head/rod and sliding valve is decreased and become zero within 7.1sec of simulation time.
From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 32 maximum braking force is 705.220KN with simulation time 7.1se. From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances.

5.7 Simulation results on minimum leakages through TVPh, TVPr & SV

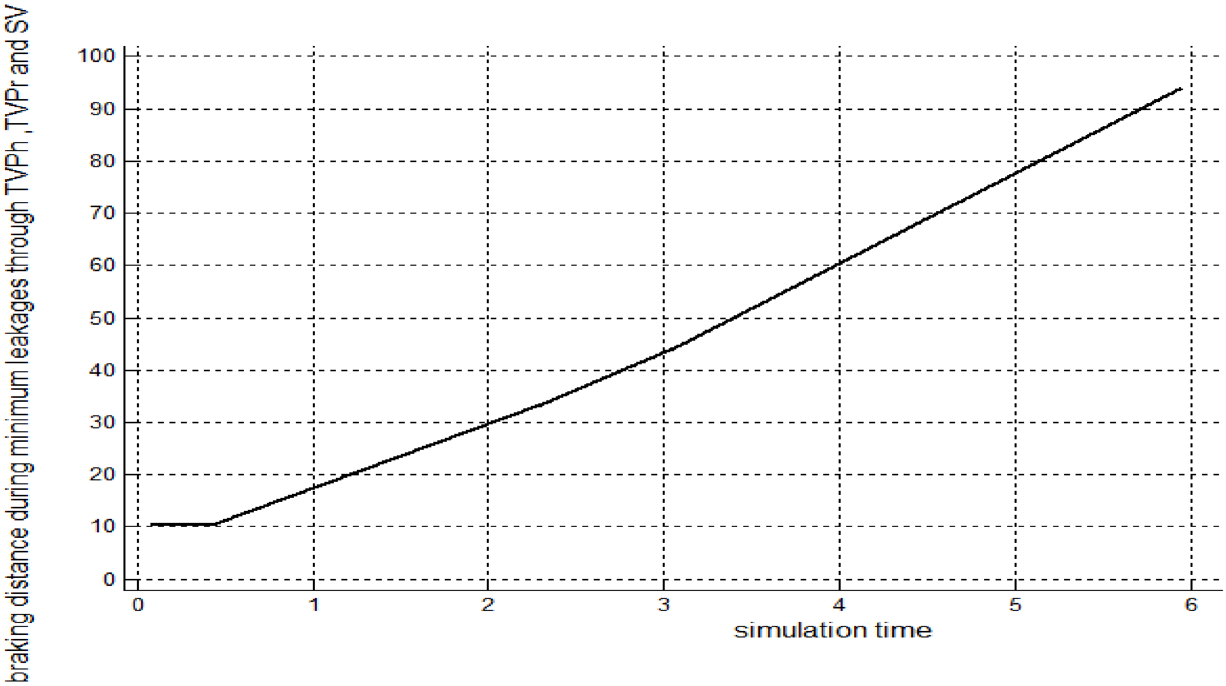

Figure 33 braking distance during minimum leakages through TVPh,TVPr,SV& VS simulation time

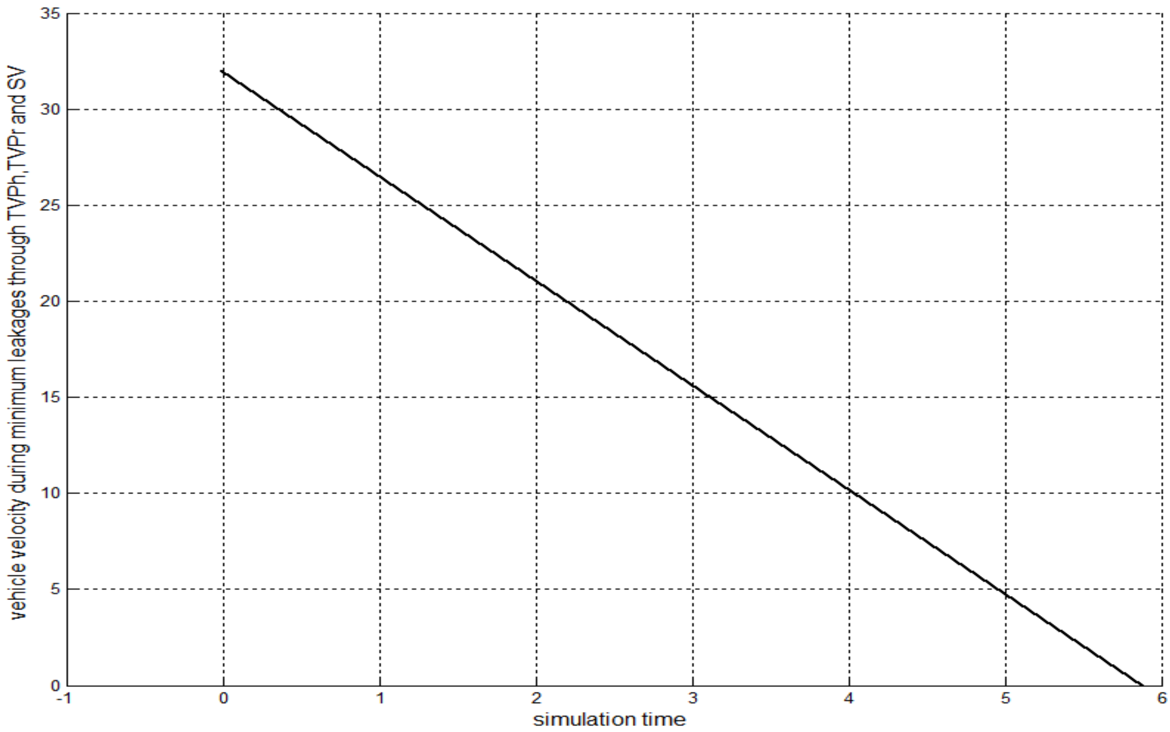

Figure 34 vehicle velocity during minimum leakages through TVPh,TVPr,SV& VS simulation time

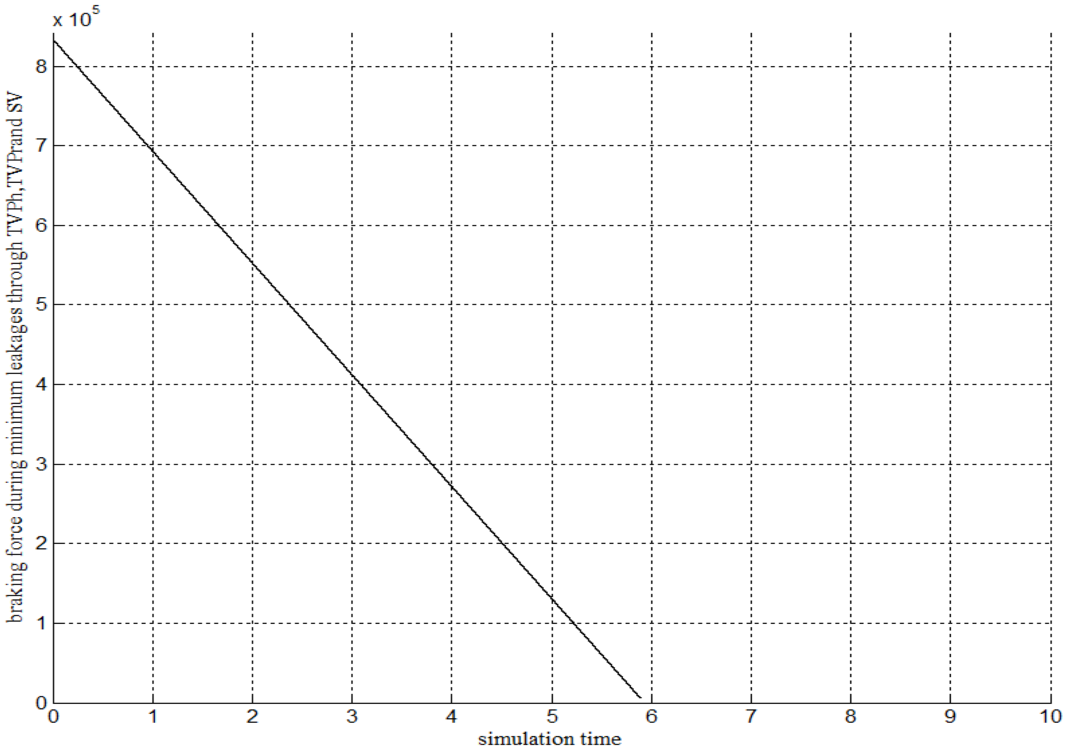

Figure 35 braking force during minimum leakages through TVPh,TVPr,SV& VS simulation time

5.8 Discussion on minimum leakages through TVPh, TVPr, & SV

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se.

From figure 33 braking distance during minimum percentage leakages through TVPh, TVPr, & SV is 98m at a simulation time of 5.94sec.

From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during maximum leakages through triple valve piston head, triple valve piston rod and sliding valve case is 5.94sec.

From figure 34 vehicle velocity during minimum percentage leakage through triple valve piston head/rod and sliding valve is decreased and become zero within 5.94sec of simulation time.

From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 35minimum braking force is842.088KN with simulation time 5.94 se. From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances

5.9 Simulation results on maximum leakages through SV, GV

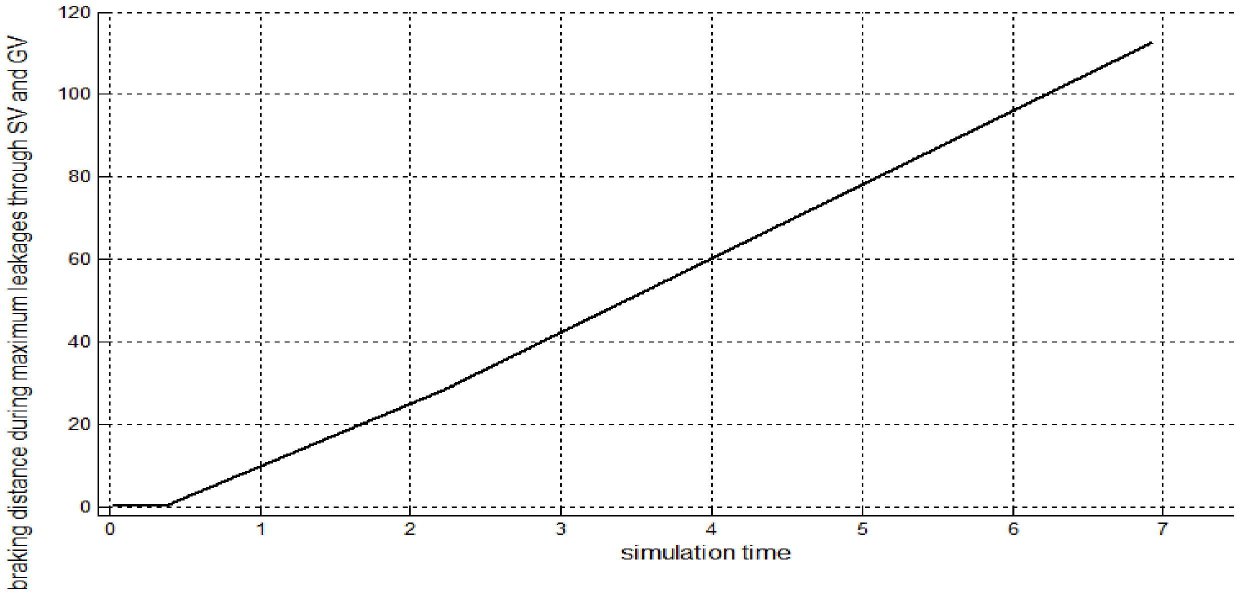

Figure 36 braking distance during maximum leakages through SV & GV VS simulation time

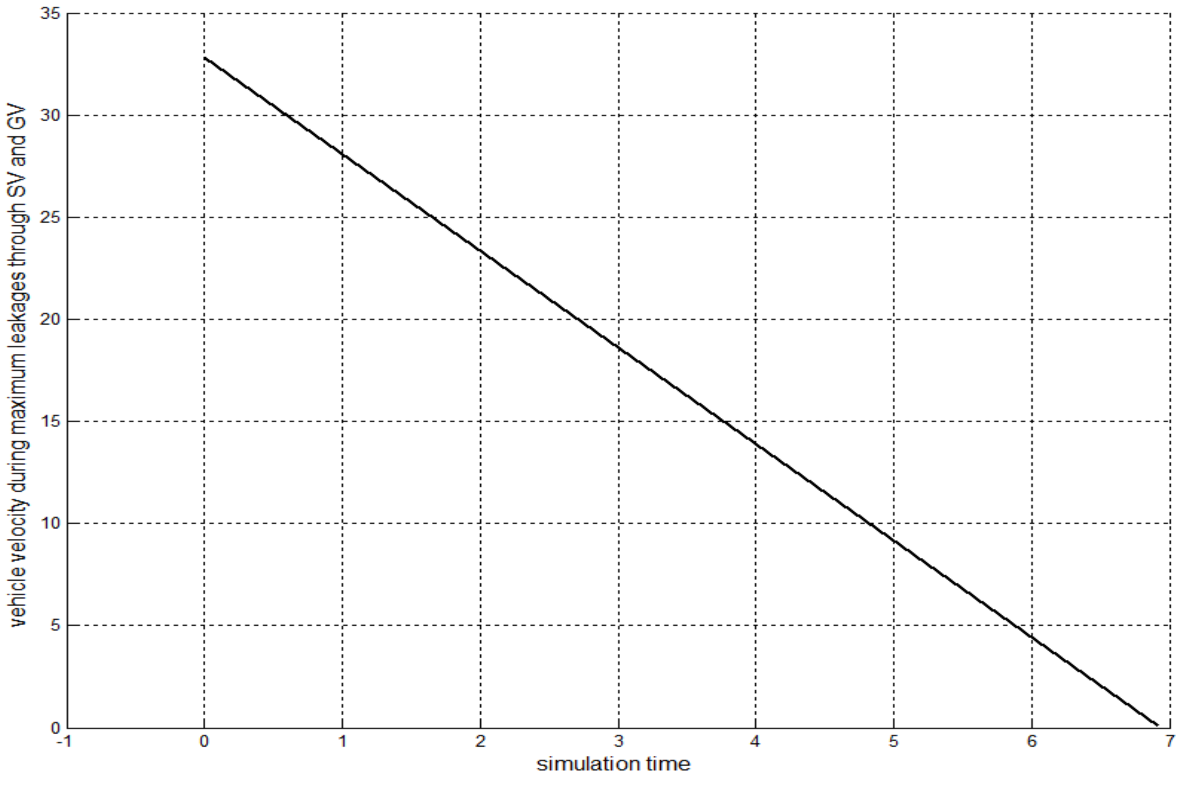

Figure 37 vehicle velocity during maximum leakages through SV & GV VS simulation time

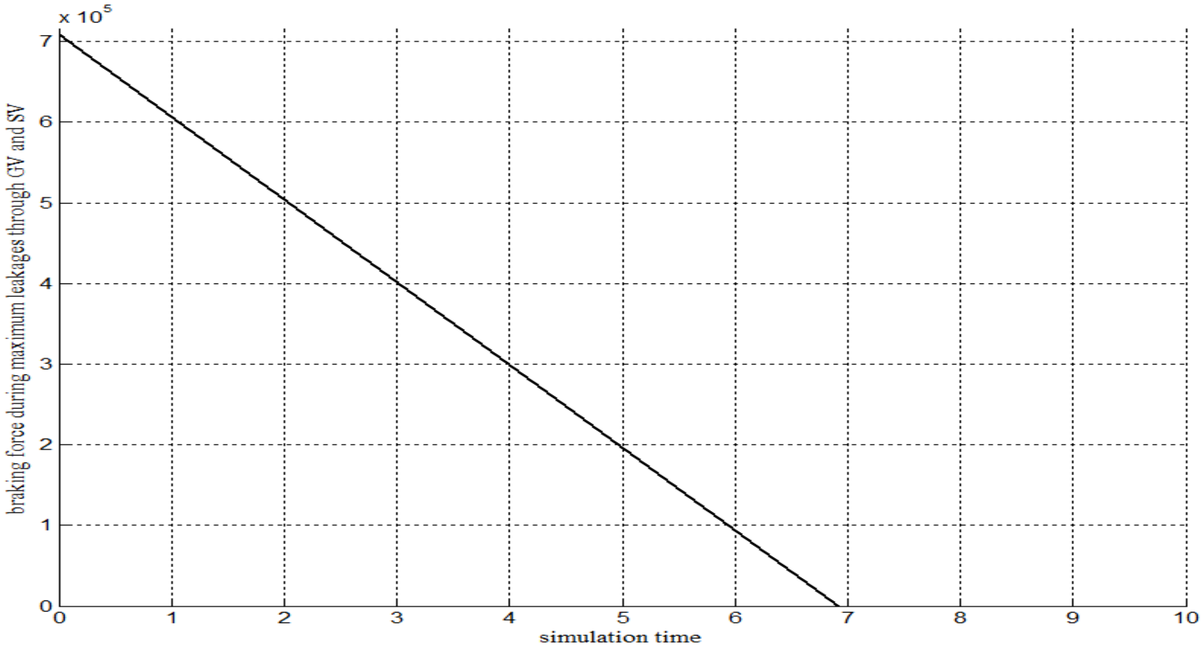

Figure 38 braking force during maximum leakages through SV & GV VS simulation time

5.10 Discussion on maximum leakages through SV& GV

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se.

From figure 36 braking distance during maximum percentage leakages through SV and GV is 116m at a simulation time of 6.98sec

Braking distance during maximum leakages through SV & GV is greater than braking distance with zero leakages through triple valve. Braking distance is increased when braking time increases.

From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during maximum leakages through sliding valve and graduating valve case is 6.98sec

From figure 37vehicle velocity during maximum percentage leakage through sliding valve and graduating valve is decreased and become zero within 6.98sec of simulation time.

From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 38 maximum braking force is716.422KN with simulation time 6.98se.From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances.

5.11 Simulation results on minimum leakages through SV, GV

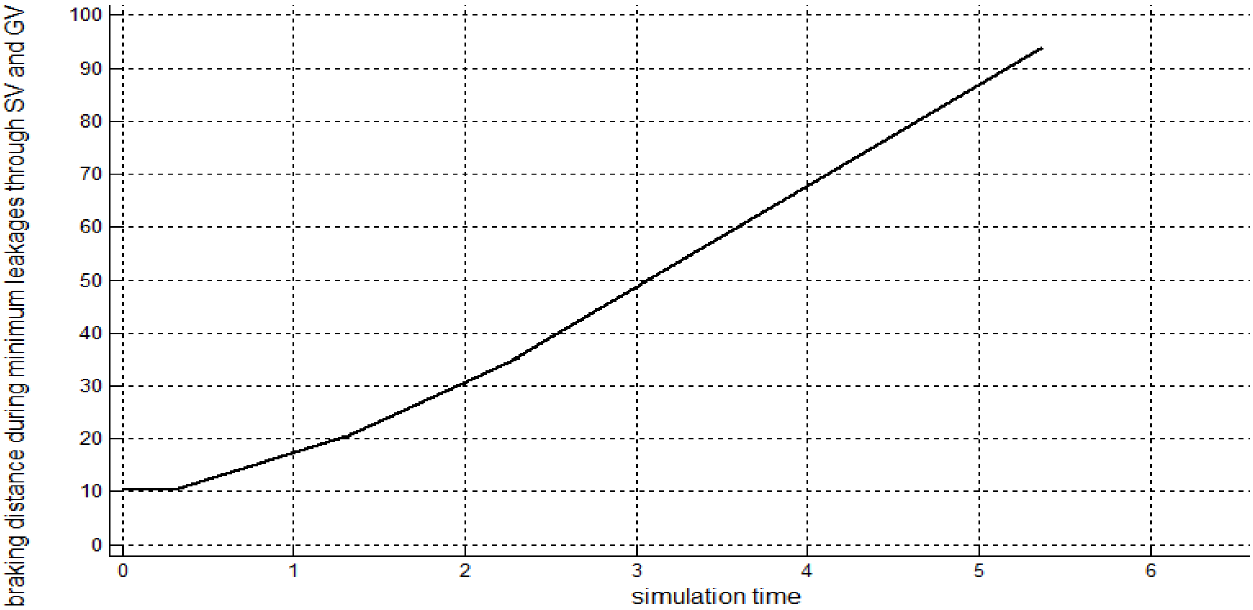

Figure 39 braking distance during minimum leakages through SV & GV VS simulation time

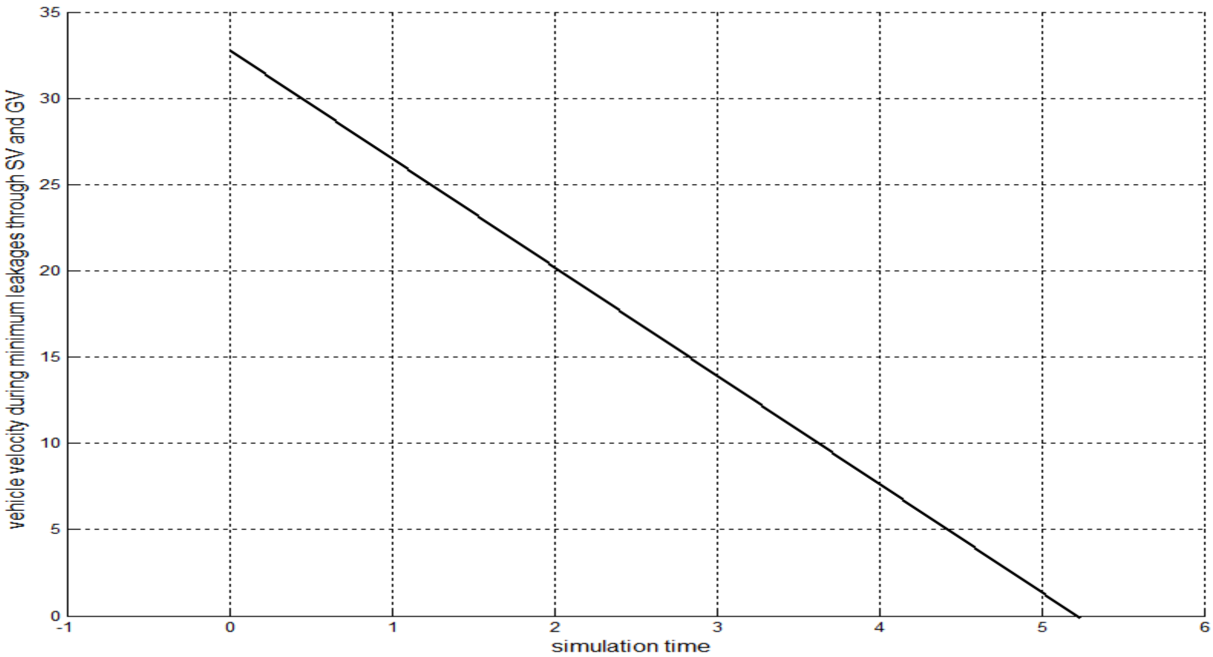

Figure 40 vehicle velocity during minimum leakages through SV & GV VS simulation time

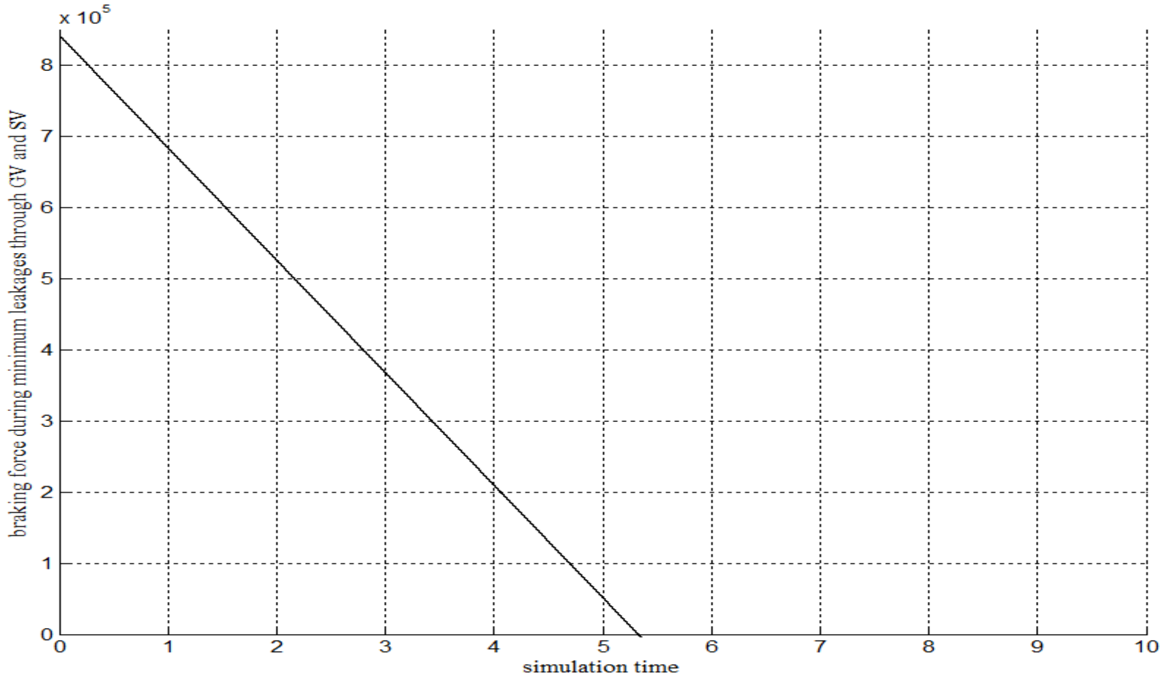

Figure 41 braking force during minimum leakages through SV & GV VS simulation time

5.12 Discussion on minimum leakages through SV& GV

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se.

From figure 39 braking distance during minimum percentage leakages through SV and GV is 116m at a simulation time of 5.26 sec

Braking distance during minimum leakages through SV & GV is greater than braking distance with zero leakages through triple valve. Braking distance is increased when braking time increases. From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during minimum leakages through sliding valve and graduating valve case is 6.98sec

From figure 40 vehicle velocity during minimum percentage leakage through sliding valve and graduating valve is decreased and become zero within 5.26 sec of simulation time.

From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 41 minimum braking force is 849.3KN with simulation time 5.26se.From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances

5.13 Simulation results on maximum leakages through TVPh & TVPr

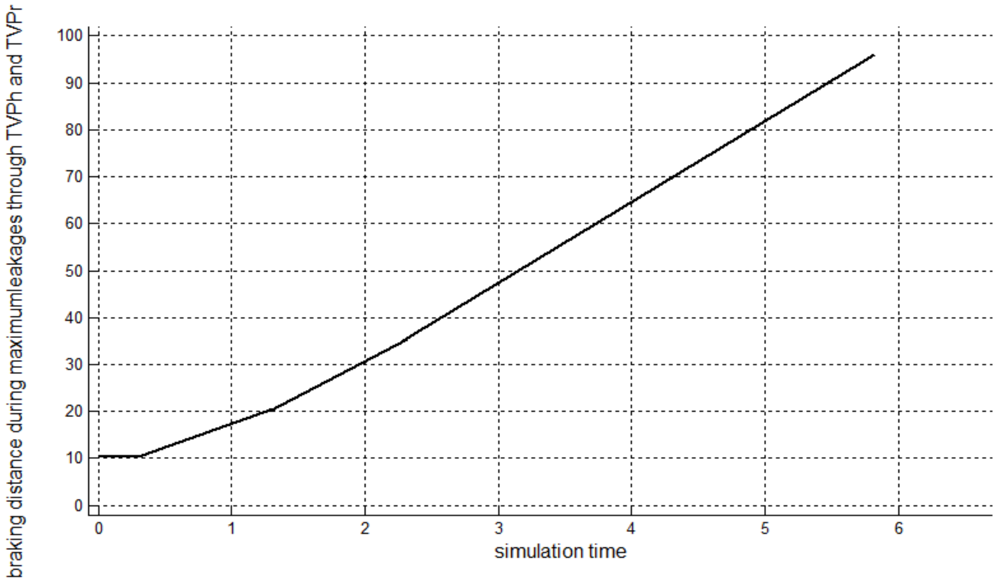

Figure 42 braking distance during maximum leakages through TVPh &TVPr VS simulation time

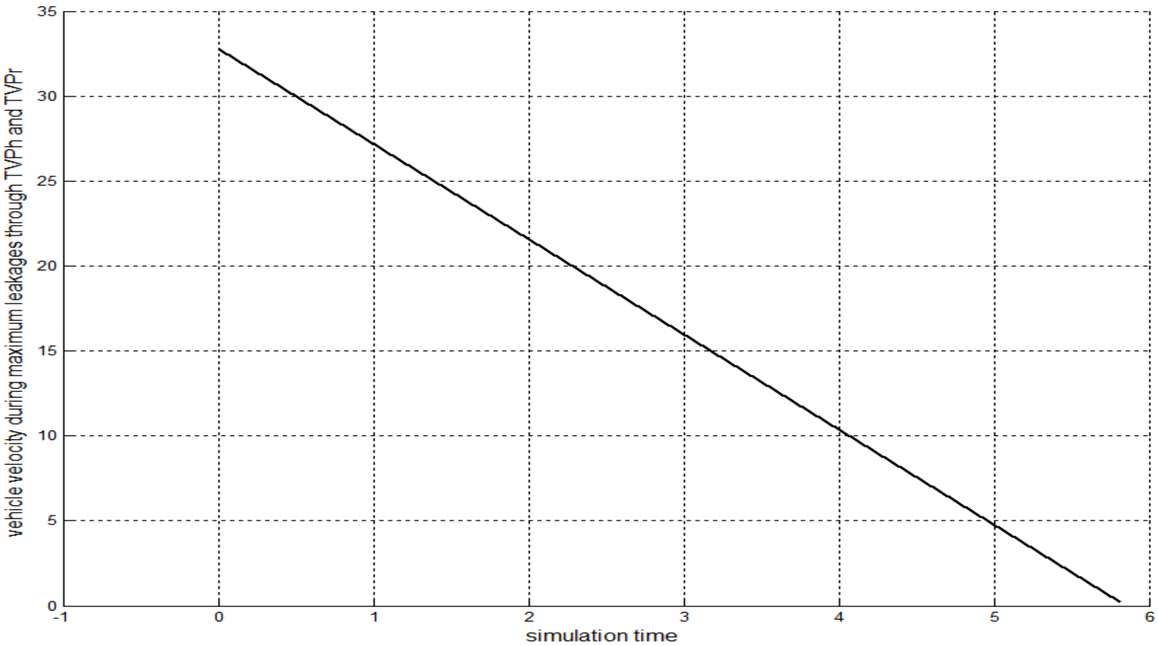

Figure 43 vehicle velocity during maximum leakages through TVPh &TVPr VS simulation time

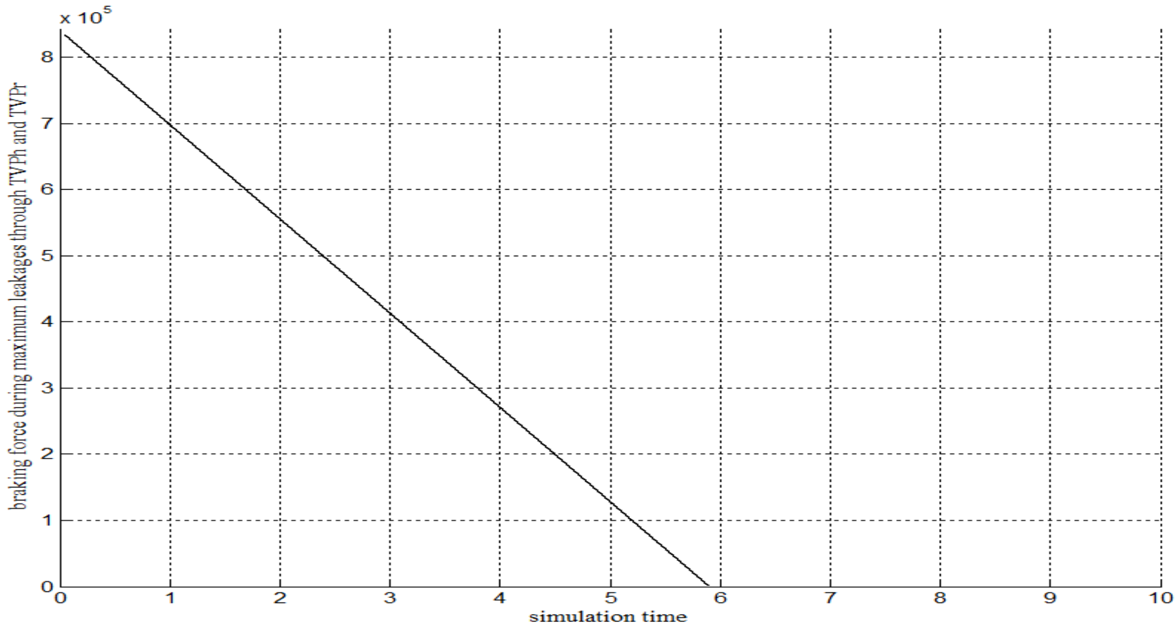

Figure 44 braking force during maximum leakages through TVPh &TVPr VS simulation time

5.14 Discussion on maximum leakages through TVPh & TVPr

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se.

From figure 42 braking distance during maximum percentage leakages through TVPh and TVPr is 98.2m at a simulation time of 5.89 sec

Braking distance during maximum leakages through TVPh & TVPr is greater than braking distance with zero leakages through triple valve. Braking distance is increased when braking time increases.

From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during maximum leakages through triple valve piston head and triple valve piston rod case is 5.89 sec

From figure 43 vehicle velocity during maximum percentage leakage through triple valve piston rod and triple valve piston rod is decreased and become zero within 5.89sec of simulation time.

From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 44 maximum braking force is 843.153KN with simulation time 5.89se.From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the "time lag")will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances.

5.15 Simulation results on minimum leakages through TVPh & TVPr

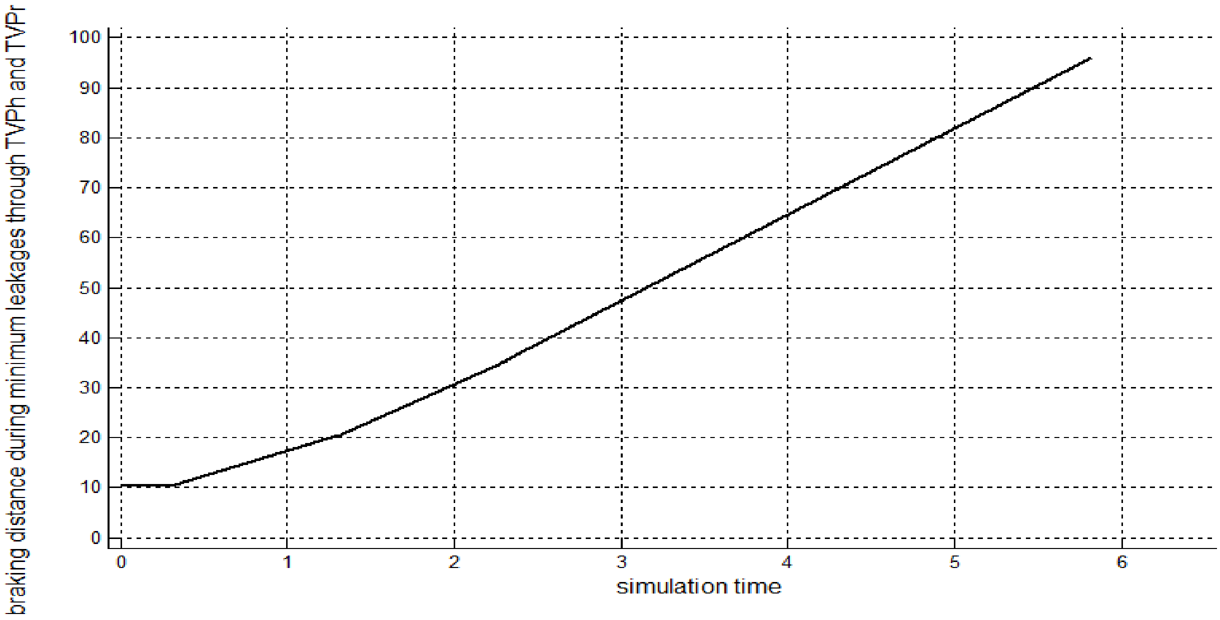

Figure 45 braking distance during minimum leakages through TVPh &TVPr VS simulation time

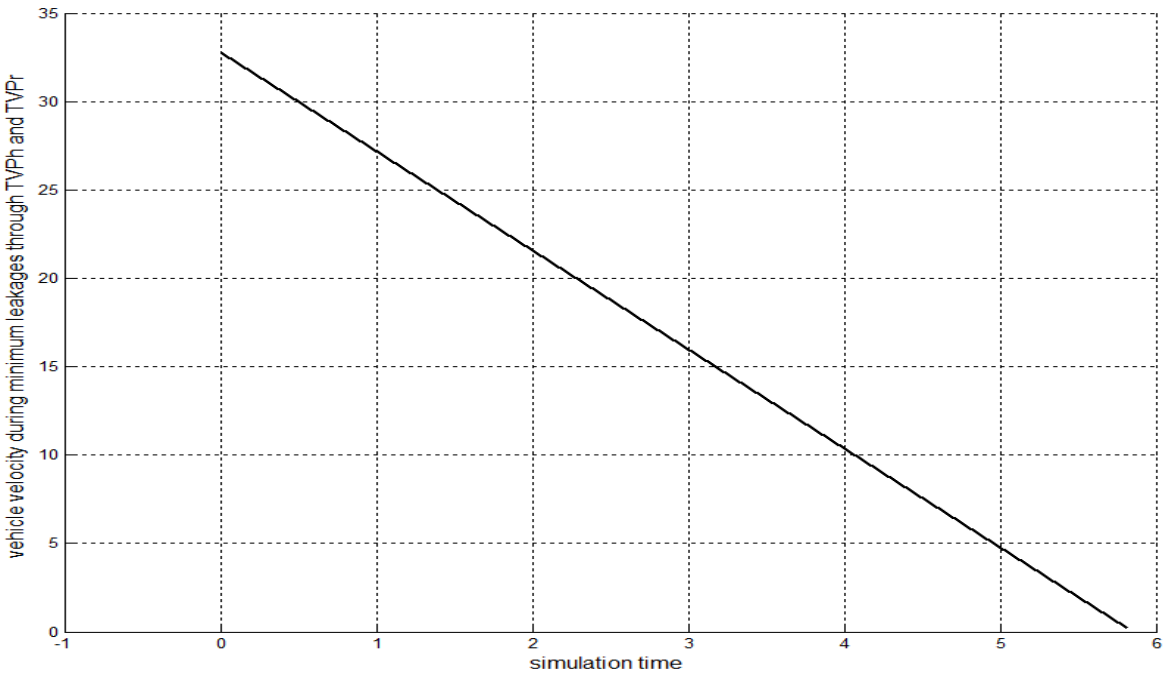

Figure 46 Vehicle velocity during minimum leakages through TVPh &TVPr VS simulation time

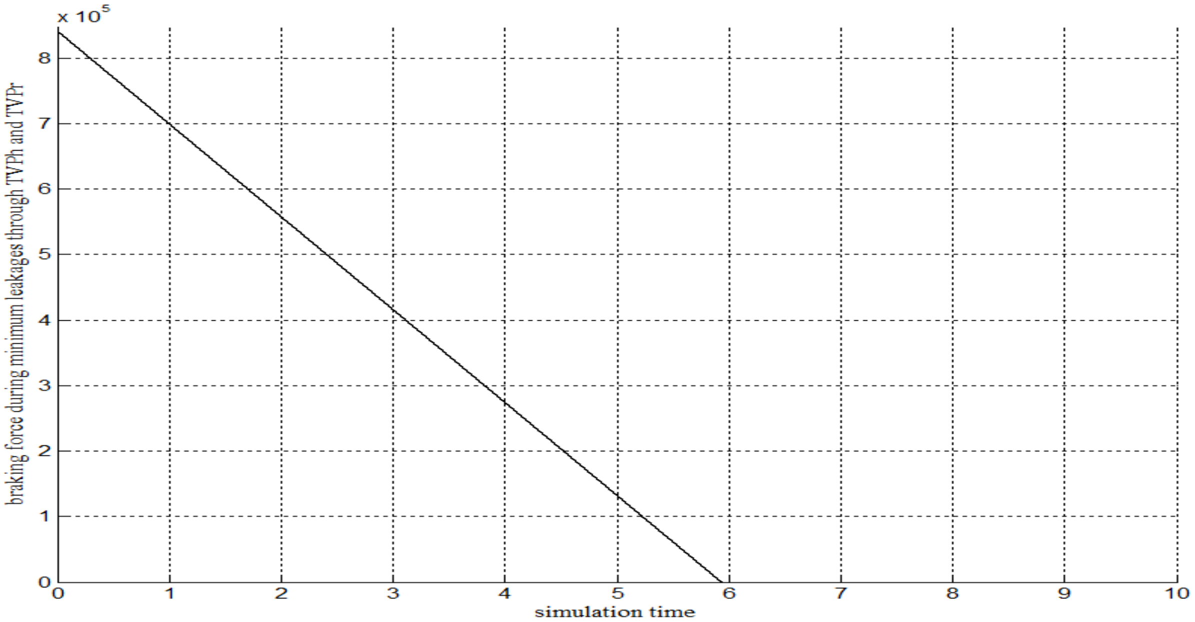

Figure 47 braking force during minimum leakages through TVPh &TVPr VS simulation time

5.16 Discussion on minimum leakages through TVPh & TVPr

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se.

From figure 45 braking distance during minimum percentage leakages through TVPh and TVPr is 98.4m at a simulation time of 5.90 sec

Braking distance during minimum leakages through TVPh & TVPr is greater than braking distance with zero leakages through triple valve. Braking distance is increased when braking time increases.

From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during minimum leakages through triple valve piston head and triple valve piston rod case is 5.90 sec

From figure 46 vehicle velocity during minimum percentage leakage through triple valve piston rod and triple valve piston rod is decreased and become zero within 5.90sec of simulation time.

From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 47 minimum braking force is846.153KN with simulation time 5.90se.From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances.

5.16 Simulation results on maximum leakages through TVPh & SV

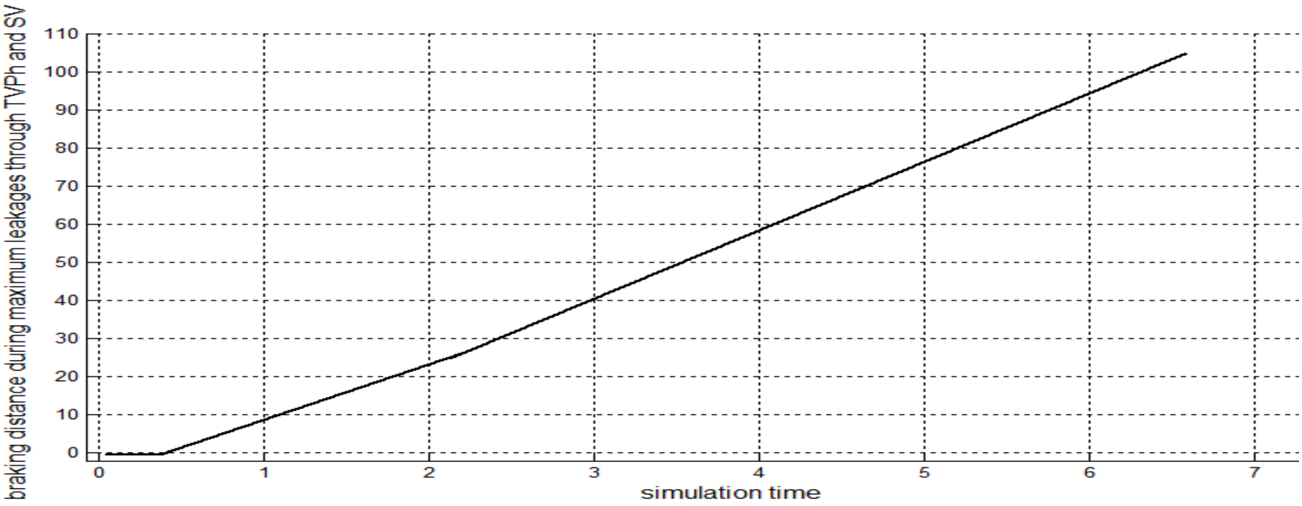

Figure 48 braking distance during maximum leakages through TVPh and SV VS simulation time

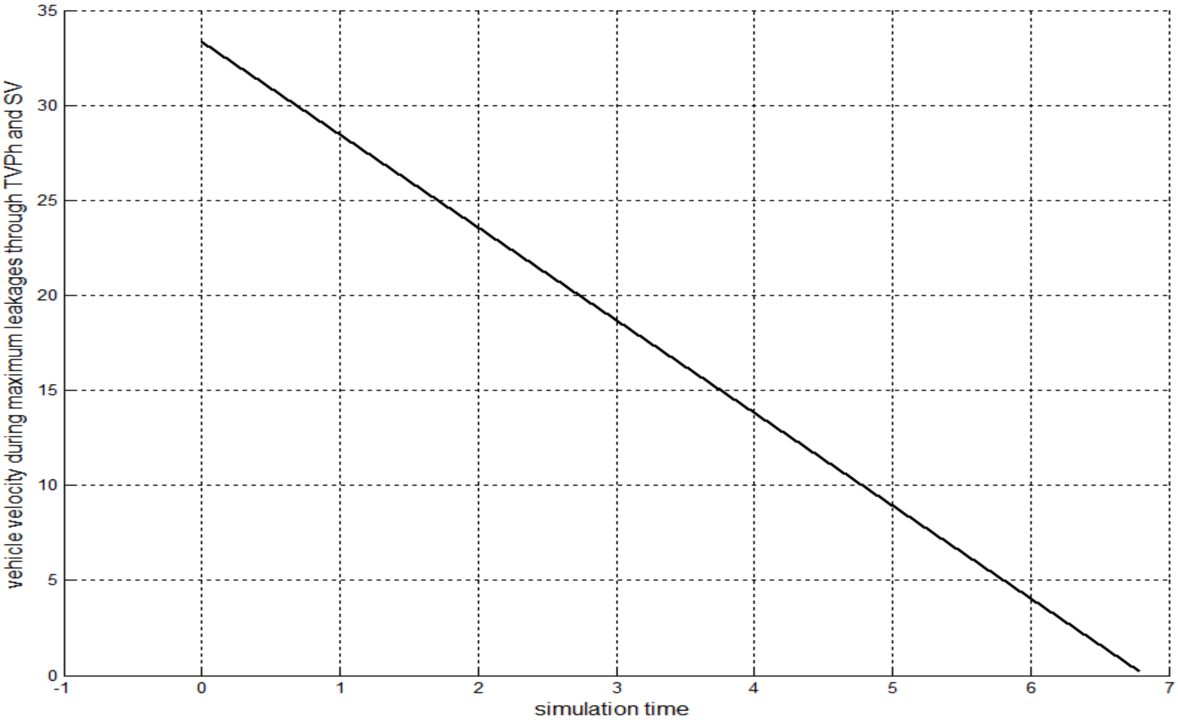

Figure 49 vehicle velocity during maximum leakages through TVPh &SV VS simulation time

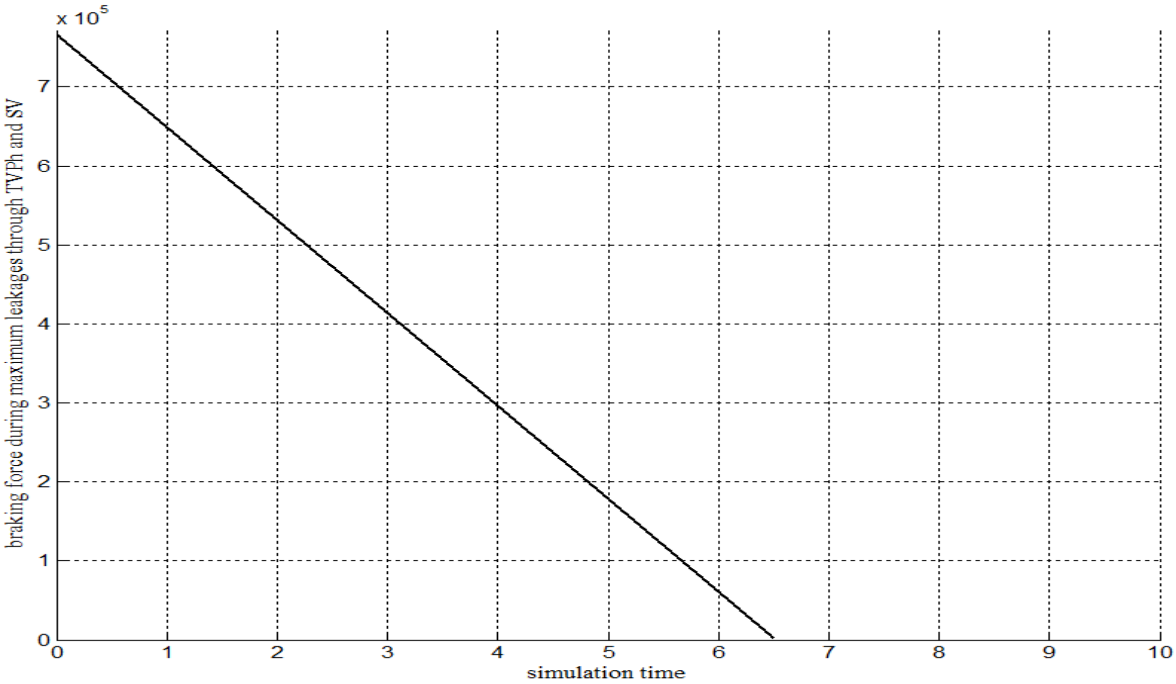

Figure 50 braking force during maximum leakages through TVPh &SV VS simulation

5.16 Discussion on maximum leakages through TVPh & SV

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se.

From figure 48 braking distance during maximum percentage leakages through TVPh and SV is 108m at a simulation time of 6.5 sec

Braking distance during maximum leakages through TVPh & SV is greater than braking distance with zero leakages through triple valve. Braking distance is increased when braking time increases.

From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during maximum leakages through triple valve piston head and sliding valve case is 6.5sec

From figure 49 vehicle velocity during maximum percentage leakage through triple valve piston head and sliding valve is decreased and become zero within 6.5sec of simulation time.

From literature [25] maximum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 50 maximum braking force is 771.5 KN with simulation time 6.5 se.From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the “time lag”)will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances.

5.17 Simulation results on minimum leakages through TVPh & SV

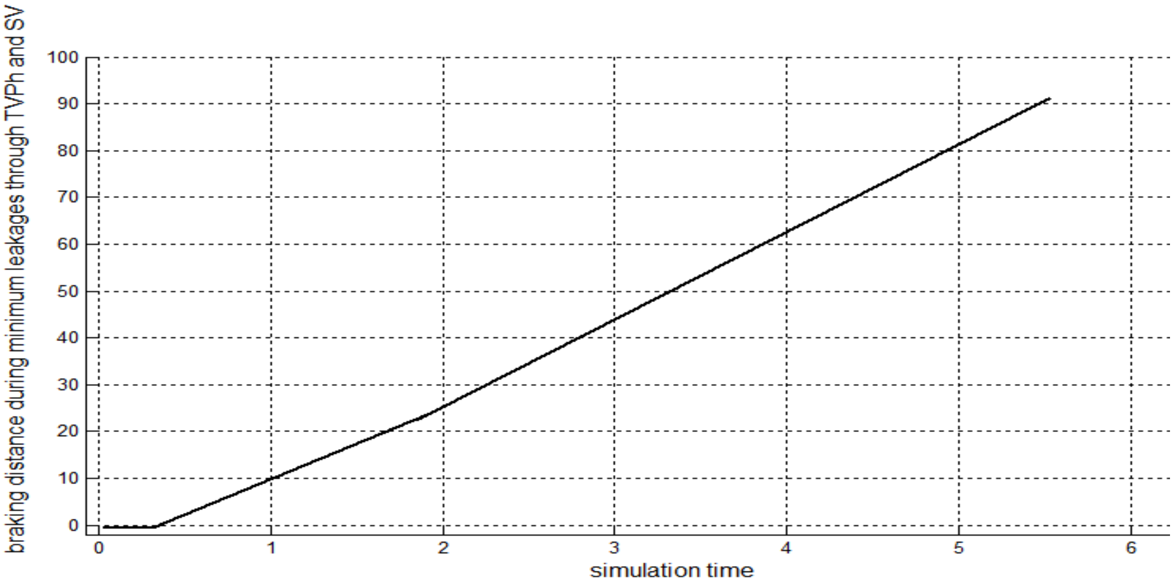

Figure 51 braking distance during minimum leakages through TVPh &SV VS simulation time

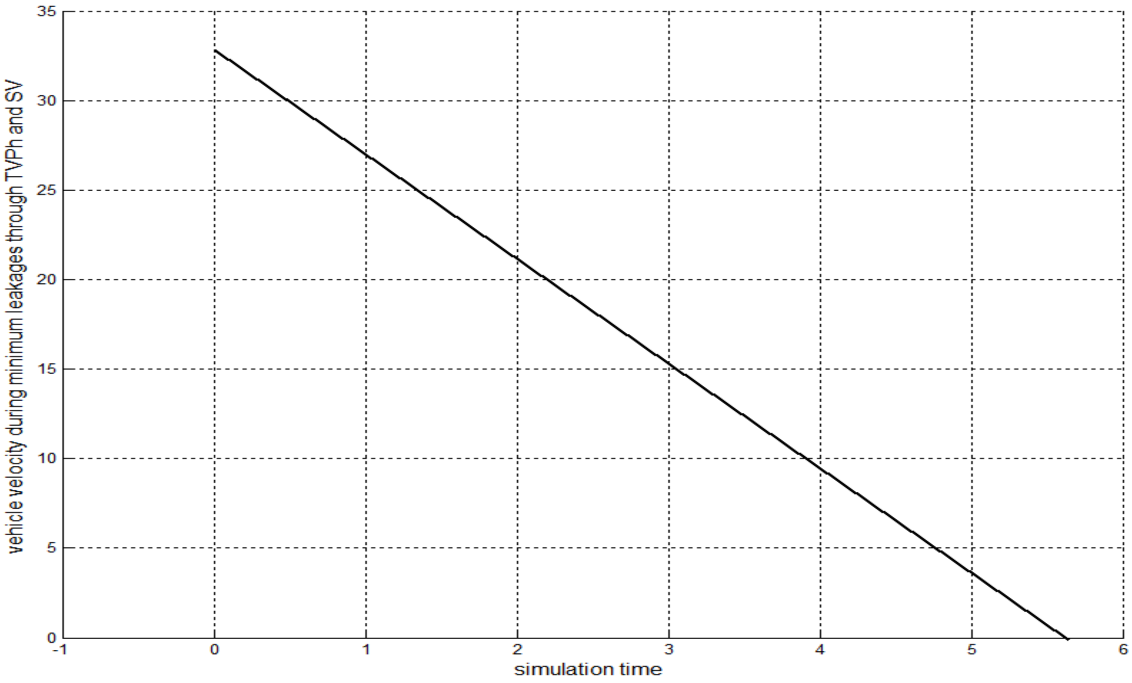

Figure 52 Vehicle velocity during minimum leakages through TVPh &SV VS simulation time

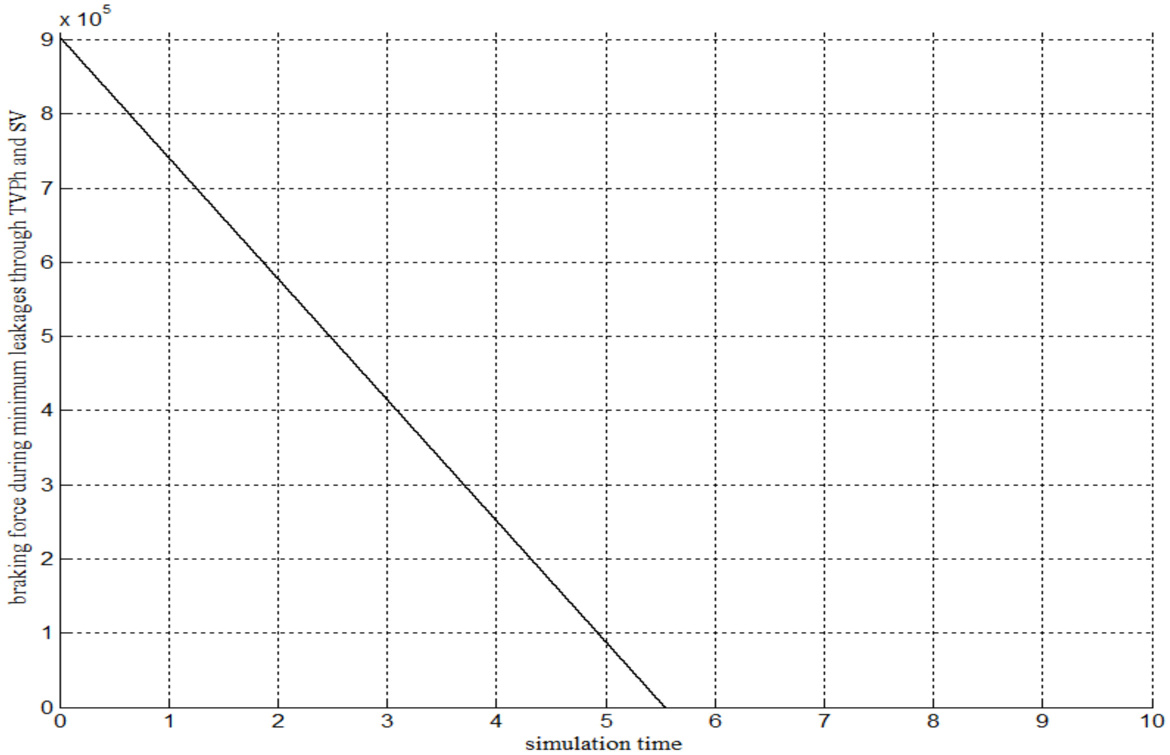

Figure 53 braking force during minimum leakages through TVPh &SV VS simulation time

5.17 Discussion on minimum leakages through TVPh & SV

From literature [24] maximum braking distance is 88.8m with simulation time of 4 to 5se.
From figure 51 braking distance during minimum percentage leakages through TVPh and SV is 91.6m at a simulation time of 5.5 sec
Braking distance during minimum leakages through TVPh & SV is greater than braking distance with zero leakages through triple valve. Braking distance is increased when braking time increases.
From literatures [24] maximum vehicle speed of 80kmph is stopped within 4 to 5sec of simulation time .since simulated result of 120kmph speed of vehicle speed during minimum leakages through triple valve piston head and sliding valve case is 5.5sec
From figure 52 vehicle velocity during minimum percentage leakage through triple valve piston head and sliding valve is decreased and become zero within 6.5sec of simulation time.
From literature [25] minimum braking force is 1600000N with simulation time 0 to 20 se during this case braking force increases as braking time increases because of no leakage through braking components especially through valve. From figure 53 minimum braking force is 910.02 KN with simulation time 5.5 se. From literature [23] Due to leakage the response of the brake system will be slower in the presence of leak (i.e. the "time lag")will be increased and also the resulting braking force generated will be lower this will lead to increased stopping distances.

5.18 Simulation results for triple valve with no leakages

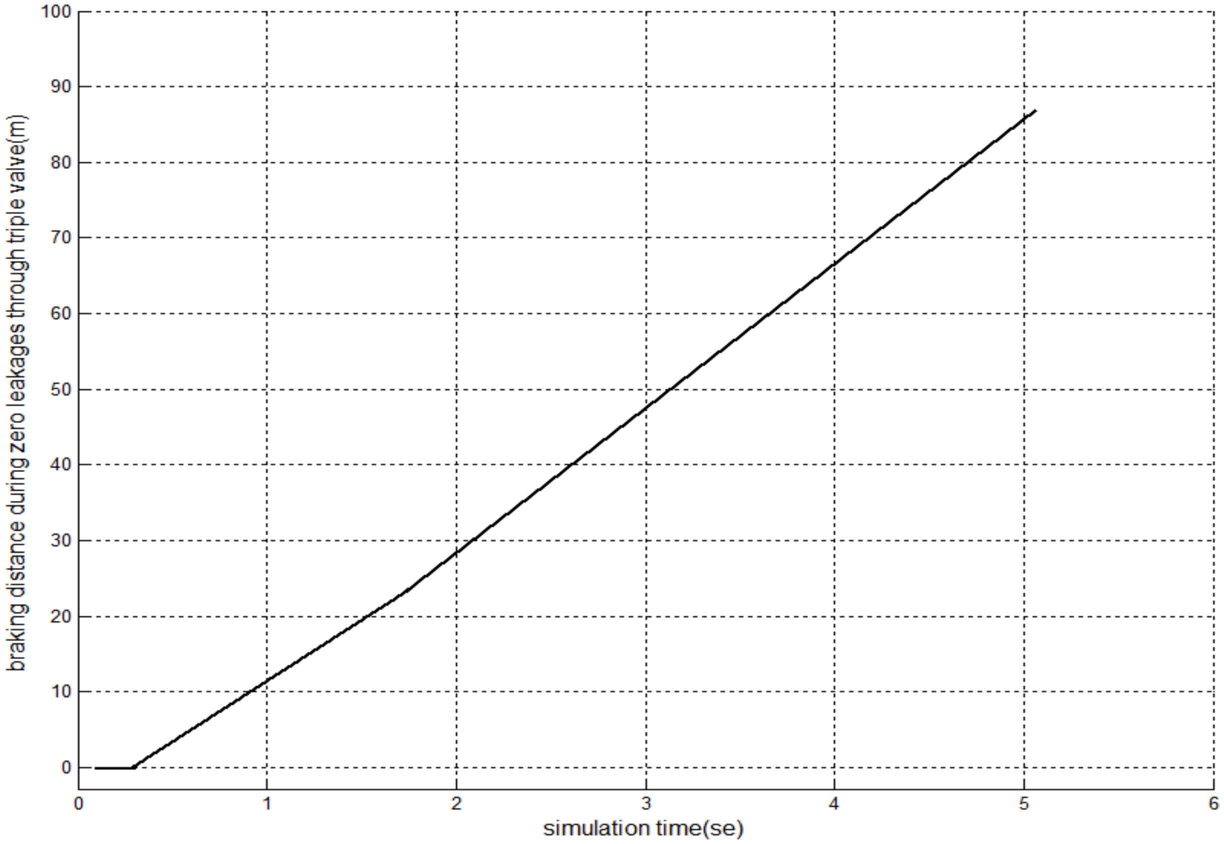

Figure 54 braking distance during zero leakages through triple valve VS simulation time

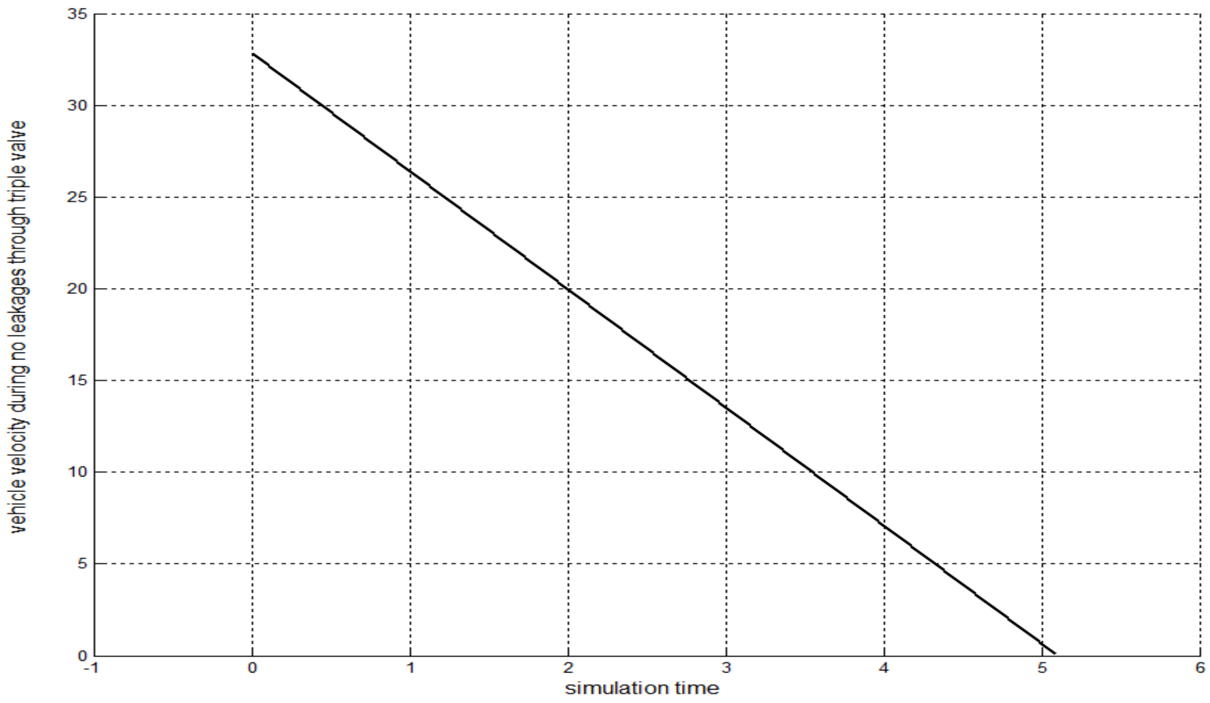

Figure 55 vehicle velocity during zero leakages through triple valve VS simulation time

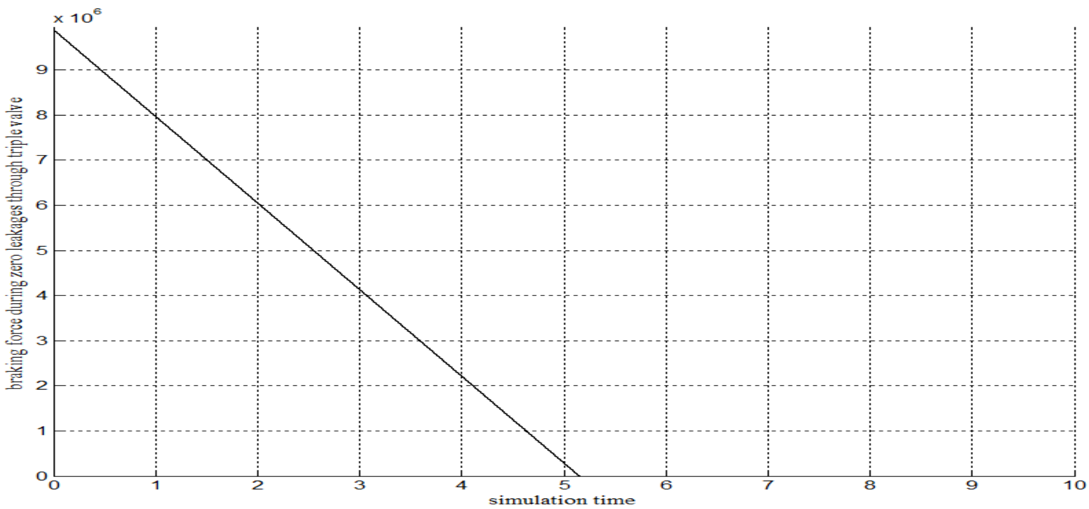

Figure 56 braking force during zero leakages through triple valve VS simulation time

5.19 Discussion on zero leakages through triple valve

From figure 54 braking distance during normal operation of triple valve is 87.3m at a simulation time of 5.23sec.

From figure 55 Vehicle velocity during normal operation of triple valve is decreased and become zero with simulation time of 5.23sec.

From figure 56 braking force at a time of normal operation of triple valve is $9.523 * 10^{5} KN$

Comparison of all braking distances and braking time with different rates of leakage through triple valve

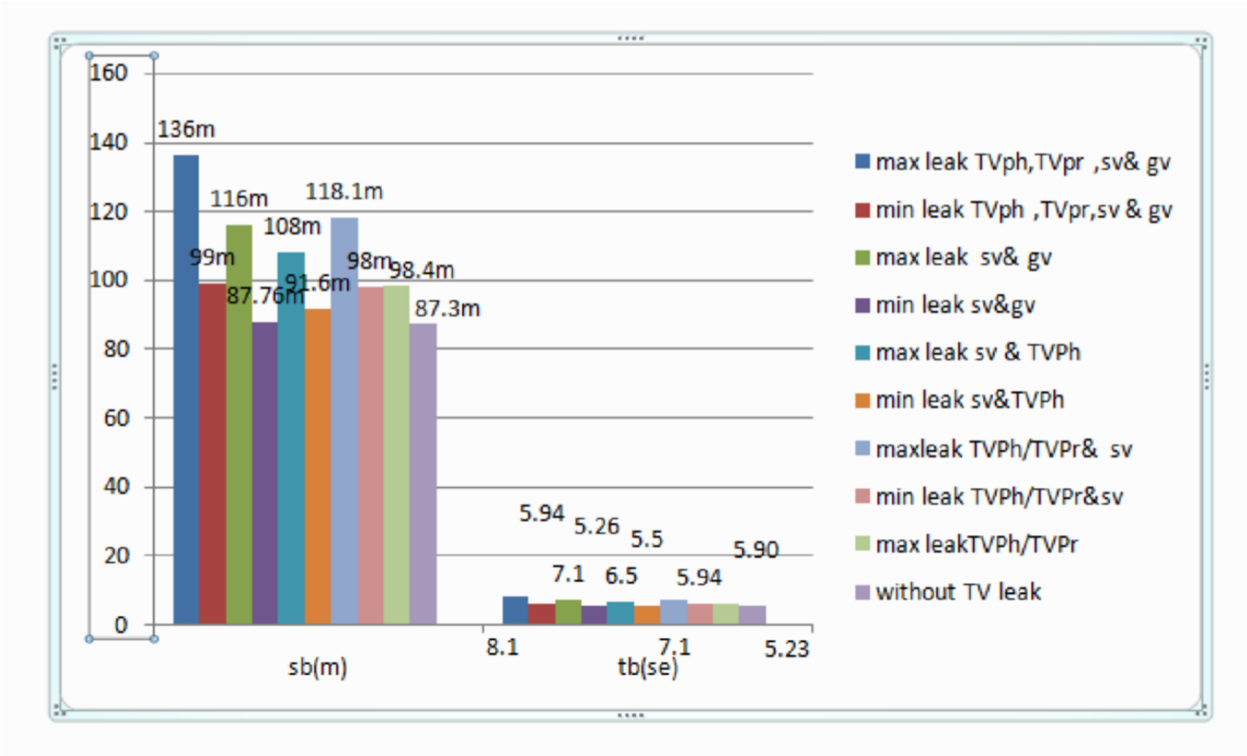

Figure 57 charts of Sb vs. tb at minimum, maximum leakages through TV & without TV leakage

CHAPTER-6

6 Conclusion and Recommendation

6.1. Conclusion

Analysis the effect of malfunction of locomotive triple valve on brake time clearly shows the effects that air leaks have at different rates through triple valve piston head, triple valve piston rod, sliding valve and graduating valves. From figure 54 braking distance during normal operation of triple valve is 87.3m and from figure 55 braking time during zero leakages through triple valve components is 5.23se and braking force $9.523*10^5$ N . But during maximum leakage through triple valve piston head, triple valve piston rod, sliding valve and graduating valve from figure 24 braking distance is 136.5m ,from figure 25 braking time is 8.1Se and from figure 26 braking force is 610.55KN.

As result shows Leakages through those components at different rates have negative effects on braking time, braking distance and braking force when compared with zero leakages through triple valve main components. Braking performances are decreased if leakages amount increases through triple valve components.

So leakages through triple valve components at different rates increases braking distances and braking times but decreasing braking forces.

6.2 Recommendation

As the simulation result shows malfunction of triple valve has a negative effect on braking system. So ERC should have to check triple valve with schedule in order to keep the triple valve from failure.

6.3 Future work

This paper presents the analysis the effects of locomotive malfunction of triple valve on brake time by using air leaks through triple valve piston head, piston rod, sliding valve and graduating valve .The analysis is done when the air leaks through those components to see the effects on braking time, braking distance and braking forces.

Therefore any one can continue this paper for analyzing the effects of air leakages through triple valve main components due to malfunction on heat generated on wheel rail contact and on passenger comfort.

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