HYBRID TRANSMISSION LINE MODELING FOR CRUDE OIL PIPLINE

BY

ADELEH KHAMES MATIN

A Thesis Submitted to British University in Dubai in Partial Fulfillment of the Requirement for Degree of Master of Science In Systems engineering

Dissertation Supervisor

Dr. Alaa Abdul- Ameer

Dubai, UAE

February, 2013

Abstract

The purpose of this study was to investigate crude oil pipeline system once modeled as lumped-distributed model and finite element, extracted from initial fluid equations. Substituting actual project values is a way to illustrate the advantages and disadvantages of each model in order to indicate the most effective way of computation.

The principal conclusion was indicated that, finite element modeling of lossy pipeline when R and G were included, and 10 km pipeline was divided into five sections, was numerically unstable. Moreover, lossless finite element model required long calculation and high consumption of storage memory.

In contrast, an examined study on lossy and lossless transmission line with much shorter computation demonstrated precise and stable transient responses. The result indicated even higher accuracy of lossy system when estimated graph intersects the original graph in three locations.

To Father , Mother and husband

Acknowledgment

It gives me great pleasure in acknowledging the advice and guidance of my supervisor, Doctor Alaa Abdul Ameer, Program Coordinator & Admissions Tutor. Also I thank Professor Whalley for his suggestion and assistance.

I cannot find words to express my gratitude toward my Husband, Hamid Fatemian, for his patience, support and encouragement to pursue this degree.

Nomenclature

Symbol	**Description**	**Unit**
D	Pipeline diameter	Inch
l	Pipeline length	meter
g	Crude oil specific weight	Gr
ν	Crude oil Kinematic viscosity	Cst
θ	Absolute crude oil Temperature	Celsius
ρ	Crude oil density	kg/m^3
V_e	Crude oil erosional velocity	m/s
R_v	Control Valve Resistance	Ohm
B	Pressure wave propagation speed	m/s
L	Pipe inductance per unit length	Henry/Meter
C	Pipe capacitance per unit length	Farad/Meter
R	Pipe resistance per unit length	Ohm/Meter
G	Pipe shunt resistance per unit length	Ohm/Mater
k_m	Motor constant	Nm/A
L_f	Motor resistance	Ohm
R_f	Motor inductance	H
ζ	Characteristic impedance	Ratio
Γ	Propagation function	Sec
h_1	Input head pressure	Pascal
h_1	Output head pressure	Pascal
q_1	Input volume of flow rate	$m^3/\sec$
q_2	Output volume of flow rate	$m^3/\sec$
T	Pressure lead time constant	Second
τ	Pressure lag time constant	Second

List of illustrations

Index

Chapter I

Introduction

1-1 System Modeling Background

System modeling is nowadays used vastly to evaluate the performance of the systems, and study the relations and interconnections between elements. Moreover, simulation is a way to illustrate different devices and their responses.

Quantitative mathematical model of the system in terms of some linear differential equations demonstrate physical parameters and their interconnections. Circuit theory is a clear example of this modeling approach. Substitution of each element parameter in a relevant equation shows the actual performance and output.

Fluid dynamic follows the same rules and can be modeled with the same equations to present all the dynamics of the system (Woods and Lawrence, 1997; Dorf and Bishop, 2001).

1-2 Lumped Element Model

Lumped system mathematically reduces the state space model of the system to a finite number of elements and its demonstration in an ordinary differential equation (ODE). On the other hand, it ignores all spatial distribution of system and deals with it as a point wise model.

In fluid lumped-parameter analysis, the pipe is divided into segments, depending on the accuracy (increasing the number of segments reduces the system accuracy), in which pressure and velocity vary with time and remain uniform over the volume of lump. Each segment is including three elements of fluid resistance, capacitance, and inductance. Normally, the relation between pressure attenuation and flow rate is nonlinear (Kevin, 1993).

Lossy transmission line can be evaluated as lumped model (T cells), or a model which is a combination of lumped and lossless distributed parameter. Dhaene and Zutter (1992) used the simple solution of thumb to select the number of cells, they stated that initial cells which cause propagation delay should be smaller than one-fifth of the shortest rise time (Dhaene and Zutter, 1992).

Lumped system model is valid where the circuit's characteristic length is less than the circuit's operating wavelength, which means that finite time that takes for signal to propagate around the circuit should be ignored and the dependent variables are the function of time.

In order to study the performance of the pipeline system, a pump which is a compact element is considered as lumped and point wise model without losses of accuracy and pipe as distributed system (Abdul Ameer, 2010).

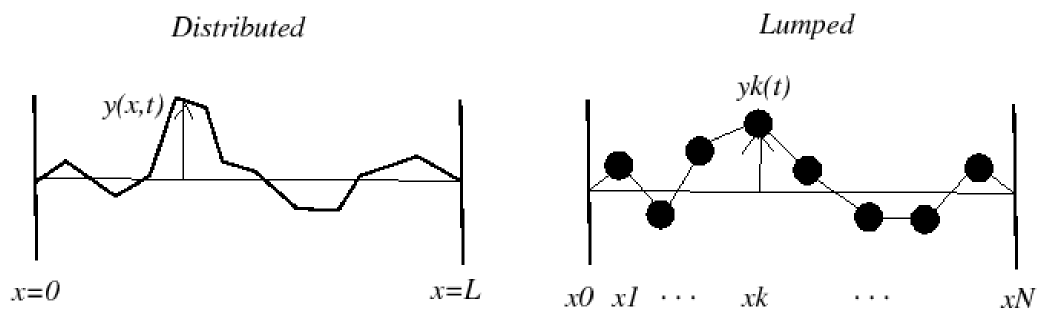


Figure (1-1) Distributed and lumped model presentation in length (https://www.ccrma.stanford.edu/~jos/NumericalInt/Lumped_vs_Distributed_Systems.html)

1-3 Distributed Element Model

Distributed element model is assumed that all the elements of the system (resistance, capacitance, and inductance), are distributed along the system where dependent variables are the function of the time, and solving is in partial differential equations (PDE). Transmission lines are a common example of the use of the distributed model.

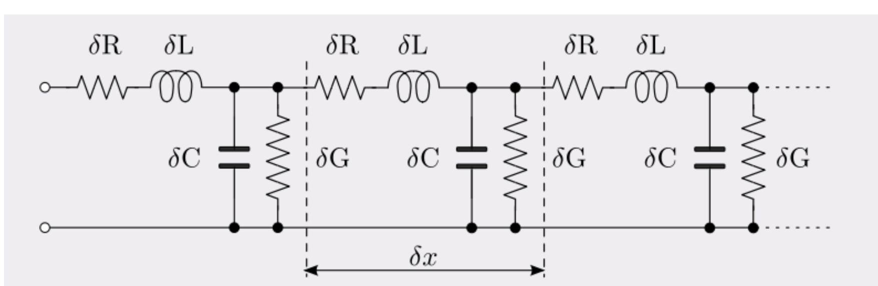


Figure (1-2) Distributed element model

(http//:/www.en.wikipedia.org/wiki/Distributed_element_model)

1-3-1 Lossless Transmission Line Model

The circuit of transmission line is just involved inductance and capacitance. As the signal propagates between conductors, each section behaves as small lumped circuit elements.

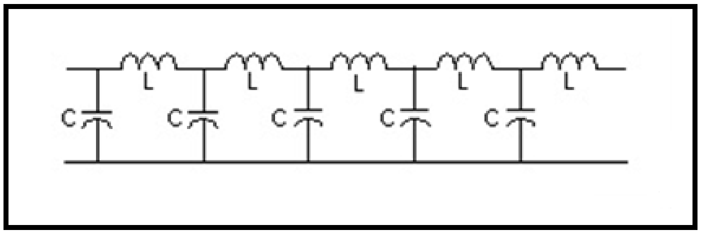


Figure (1-3) Lossless Transmission Line Model

(Retrieved from http://www.ece.uci.edu/docs/hspice/hspice_2001_2-269.html)

1-3-2 Lossy Transmission Line Model

Including losses and dissipation as series and shunt resistance shows some attenuation in system response, which will be explained vastly in chapter V.

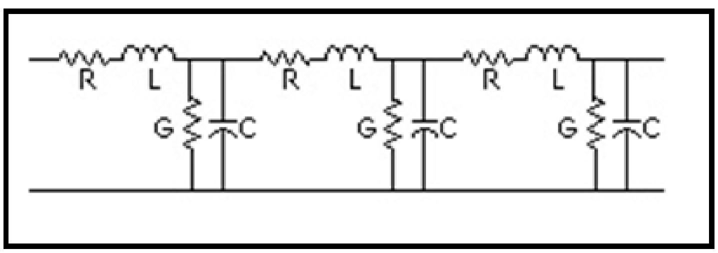


Figure (1-4) Lossless Transmission Line Model

(http://www.ece.uci.edu/docs/hspice/hspice_2001_2-269.html)

1-4 Lumped -Transmission Line Model

Applying network of lumped parameter component model helped the simulation of fluid power system which is illustrated in an ordinary differential equation (ODE). In order to have all lumped parameters for transmission line, the approximation of partial differential equation (PDE) is required. Studies of the fluid transmission line by linear PDE started by Stecki and Davis for the first time (Stecki and Davis, 1986).

In 1988, transient response of pressure in servo valve, once it is initially opened and suddenly closed was studied by Tadmori and Watton who reviewd four differential methods of time domain analysis. Paper proved that characteristic and modal analyses are the powerful techniques in higher complexity (Watton and Tadmori, 1988).

It has been proved that fluid transmission line and fitting have significant effects on dynamic and steady state behavior of systems in which the distributed parameter model is the most accurate model of it. Since the distributed parameter tends to be very complex by increasing the length, Bartos (1992) developed the lumped parameter model for the short fluid transmission line and applied it on servo hydraulic system of deep space network (DSN) of seventy meters antennas (Bartos,1992).

One dimensional distributed parameter model of a uniform rigid fluid transmission line with laminar flow was introduced for the first time by Goodson and Leonard (1972) as following:

$$\begin{bmatrix} p_a(s) \\ Q_a(s) \end{bmatrix} = \begin{bmatrix} \cosh\Gamma(s) & Z_c \sinh\Gamma(s) \\ \dfrac{1}{Z_c(s)}\sinh\Gamma & \cosh\Gamma(s) \end{bmatrix} \begin{bmatrix} p_b(s) \\ Q_b(s) \end{bmatrix} \qquad \text{1-4-1}$$

Where $\Gamma(s)$ and $Z_c(s)$ are the presentation of propagation and impedance respectively. Accordingly, it was applied by Yang and Tobler in 1991 to compare the result of transfer function and state space transmission lines when frequency dependent damping and natural frequency dependent modification are included (Yang , Tobler,1991).

Trikha (1975) published a paper which presented linearized two-dimensional solution by applying momentum and continuity equation of Navier Stoke in which the constructed block diagram was as figure (1-5):

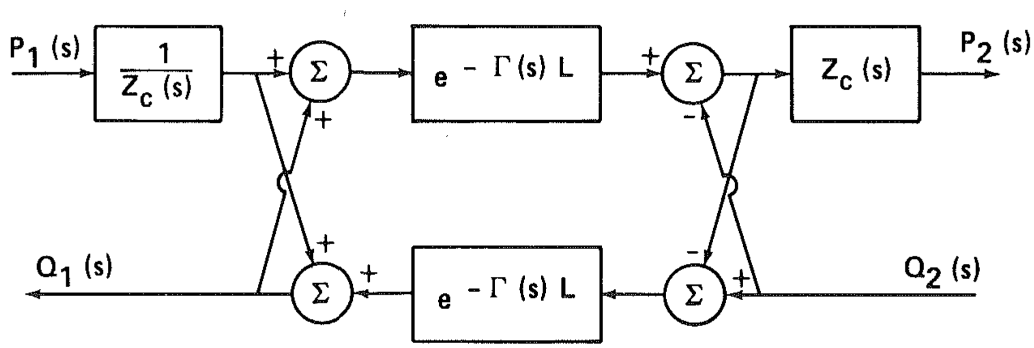


Figure (1-5) Representing the two port transmission line, adapted from Trikha (1975)

Frequency-dependent friction included in mathematical calculation and the effects of fluid viscosity in laminar flow were evaluated, and the result demonstrated that the computation does not need more computer storage than steady state friction inclusion (Trikha, 1975).

The inclusion of wall shear stress in the calculation of one-dimensional transient laminar pipe flow by applying Navier Stroke equation was introduced by Zielke. The calculation and experimental result were compared and showed the accurate prediction of distortion achieved in the experiment. Experimental set up can be found as follow:

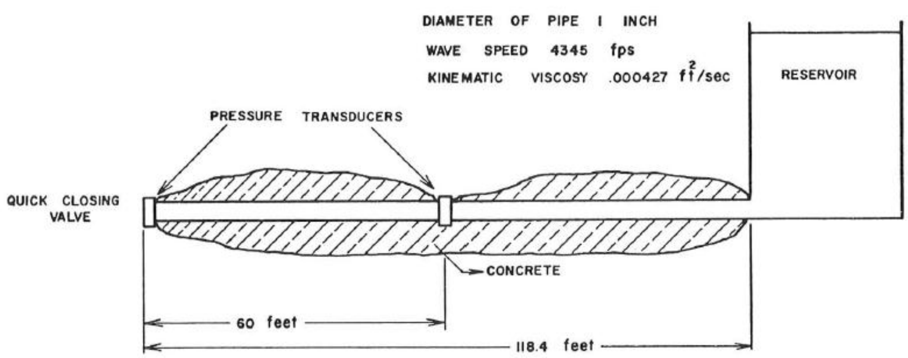


Figure (1-6) Experimental work set up, adapted from Zielke (1968)

The paper which was published by Whalley, Abdul-Ameer and Ebrahimi (2011), was the illustration of milling machine system as one-dimensional lumped-distributed model of which lead screw was playing mass–inertia and stiffness roles. The motor and rest of elements were assumed to be lumped and point wise.

Mathematical model was introduced as below where input was considered as machine motor torque and output as table velocity.

$$\begin{bmatrix} T_1(s) \\ T_2(s) \end{bmatrix} = \begin{bmatrix} \zeta\, W & -\zeta(W^2(s)-1)^{\frac{1}{2}} \\ \zeta(W^2(s)-1)^{\frac{1}{2}} & -\zeta W(s) \end{bmatrix} \begin{bmatrix} w_1(s) \\ w_2(s) \end{bmatrix} \qquad \text{1-4-2}$$

Simulation graph of table velocity was almost meeting the experimental graph and showed the establishment of model accuracy during both transient and steady state response. Authors applied the same techniques for three-dimensional movement in X,Y, and Z direction of the table where output response contained all the transient disturbances of the same axis and response followed sin(t) and cos (t), X and Y axes voltage changes (Whalley ,Abdul-Ameer and Ebrahimi, 2011).

Introducing a new method for modelling of hydraulic pipeline system based upon a lumped – distributed parameter presented by Abdul Ameer. The paper illustrated the dynamic behaviour of the hydraulic pipeline system from momentum and continuity equations when two kinds of fluids such as BP HLP 32 and BP Energol EMY are employed. R_f was extracted from the below equation as the function of time series resistance:

$$R_f(s,x) = [R_0 + \frac{K_f}{M_j / N_j}] \qquad \text{1-4-3}$$

And M_j and N_j as constant value of Taylor et al (1997).

Calculated R_f and h_f , substituted in (1-4-3) and the simulation result of two fluids was compared with experimental results, and showed the accurate agreement (Abdul Ameer, 2001).

1-5 Fluid Transmission Line Background

Including losses and dissipation as series and shunt resistance show some attenuation in the system response.Fluid and electrical transmission line theory has been established since starting of 20th century. Telegrapher's equation which was introduced by Heaviside, found in contrast to circuit theory. His equation was implies the way of distributing main parameter such as inductance and capacitance of the system along the length of the line.

Transmission line model which was introduced by him extracted from Maxwell equations and proved how the system works precisely by just including propagation operator Γ and the characteristic impedance ζ (Kirshner and Katz, 1887).

In order to qualify the dynamic behavior of the system precisely, a fluid transmission line system required to represent in distributed parameter model. Initial equations of fluid transmission line theory simply extracted from Navier-Strokes equations (Fung, 1994).

Fundamental equations follow the basic laws of conservation of momentum, mass, and energy:

- Energy: The dissipation of heat
- Continuity: The conservation of mass
- Momentum: The acceleration of fluid module

Since compressibility and incompressibility is not considered in Navier-Strokes equations, the new equation of State has to apply in the total solution, which is demonstration of compressibility of the fluid.
Including the viscous friction and heat transfer effect in the solution is introduced by Iberall for the first time (Iberall, 1950).

First order or classical model solution is produced by Gerlach (Gerlach, 1969).

Gerlech model is used later by Goodson and Leonard as reference to develop varies distributed parameters model (Goodson and Leonard, 1972).

Dissipative model which designed by Woods is considered to be the most accurate system until 1981 (Gerlach, 1981).

Overgrowing requirement of electric power with transmission resources increased the application of (HVDC) rather than AC due to less voltage drop and cost effective method over long distances. The transmission and distribution is utilized the delivery of fluid from sources to consumers (Douglas, Katrina and Juan, 2005).

1-6 Fluid Parameters and Description

1-6-1 System Static

Since no shear stresses affecting the fluid at rest, no distortion occurs. The only pressure affecting the fluid is the normal stress of gravity which is equal to volume force of the fluid element due to the gravity.

1-6-2 System Dynamic

Studying systems of dynamic is a way to evaluate included components in the system in order to understand the time dependent behavior of them. Systems devices analyze and model to differentiate the effect of each element on the whole system behavior. Finally, control system comes to point of view to let the elements work together efficiently. Fluids are divided into two groups of those which do not compress and density remains constant under pressure which is called liquid and the other which compresses and deforms or changes density and is called gases. Systems which are working with uncompressible fluids are called hydraulic, and those which work with compressible fluids are called pneumatic.

1-6-3 Fluids in Motion or Fluid Dynamic:

1-6-3-1 Pressure

Pressure is the force per unit area, which dispenses by fluids. The EPS and SI unit of pressure are lb/ft^2 and the Pascal ($1Pa = 1N/m^2$) respectively. Measuring pressure itself in the system is impossible. The pressure that is normally achieved with different ways of measurement is Gage Pressure, which was introduced as a difference between absolute pressure and atmospheric pressure.

Hydrostatic Pressure is the pressure that exits in the fluid at rest. It is caused by the weight of column of fluid. For example, the hydrostatic pressure at the bottom of tank with h height is rgh plus atmospheric pressure above the tank which gives a total of $rgh + P_a$

1-6-3-2 Density

Density of a substance is the ratio of the mass of a given amount of substance to the volume it occupies. Change of density may be achieved both by a change of pressure and temperature.

1-6-3-3 Viscosity

Fluid tends to resist against any force, which causes the movement of the layer over each other (Shear Force). Research shows that different substances behave differently against forces. Some fluids offer greater resistance than others. Light fluids like water, petro, and paraffin have small viscosity and heavy fluids own large viscosity.

1-6-3-4 Compressibility

Changing the applied pressure on any kind of substance causes attenuation in the volume of fluids. The rate of compressibility of fluid characterized as Bulk modulus of elasticity which is calculated as below:

$$K = -\frac{dP}{dV/V} \qquad 1\text{-}6\text{-}1$$

Where dP demonstrates the small increase in pressure over the small decrease in volume. Since rise in pressure declines the volume, dV is always negative. Accommodating minus in the formula gives a positive value of K.

1-6-3-5 Motion

1-6-3-5-1 Momentum and Momentum Equation

Fluid movements are all caused by exerting forces. The air moving over the wings exerts the lift force on an aircraft. A jet of water from a hose exerts a force on whatever it hits. Analyzing motion in the fluid shows that fluids act the same as solid and all follows Newton's second motion law.

The momentum equation is the statement of Newton's second law and relates to the submission of force which acts on the element of fluid to its acceleration or the rate of momentum.

Considering one dimensional pipe model with time, t, length of pipe, x, head pressure, H& sectional velocity, V, momentum equation expressed by Zielke is as below: (Zielke, 1968).

$$g\frac{\partial H}{\partial x}+V\frac{\partial V}{\partial x}+\frac{\partial V}{\partial t}+gh_f=0 \qquad \text{1-6-2}$$

1-6-3-5-2 Continuity Equation

The most applicable method used to analysis of the uniform flow is continuity of flow which is derivation of the fluid equations when complexity and direction of flow is neglected.

Once steady flow exists in the system and conservation of mass is applied, the continuity of flow assigned as the equal velocity at all cross section areas and if cross section areas are not equal, velocity is proportional to the areas of cross sections.

Hence when the flow is constant the Continuity Equation defined as:

$$\frac{\partial V}{\partial x}+\frac{g}{a^2}(V\frac{\partial H}{\partial x}+\frac{\partial H}{\partial t})+\beta V=0 \qquad \text{1-6-3}$$

Where g is gravity, a wave speed and β as taper of pipe.

1-6-3-6 Basic Characteristics of Fluid in Motion

1-6-3-6-1 Flow Parameter Variation

Fluid parameters like density, velocity, and pressure could change from place to place along the flow rate. Demonstrating the location of each of above parameters could be in coordinate system. For instance, velocity V is the function of X, Y, Z and t.

Mathematically, it can be written as V(x, y, z, t) or P(x, y, z, t) as pressure.

If the above parameters do not change form point to point, the flow is said to be uniform. If change does occur from point to point, the flow is said to be non-uniform.

1-6-3-6-2 One, Two, and Three-Dimensional Flow

Considering density, velocity, and pressure, variables in all coordinates make the systems three-dimensional, which are complicated to calculate.

One-dimensional flow is the system that all of the parameters are expressed as the function of time and one space coordinates only.

1-7 General Description of Fluid Flow

1-7-1 Steady and Unsteady Flow

The flow that all the condition of pressure, velocity, and cross section differ from point to point, but does not change with time, is called steady. If at any point in the fluid, conditions change with time, then it is described as unsteady.

1-7-2 Compressible and Incompressible Flow

Considering this fact that all fluids are compressible and density changes as pressure changes make the calculation extremely complicated. To simplify, analyzing the flow it is usually assumed that change in density is too small that can be neglected in the system and deals with it as incompressible.

1-7-3 Damping in the System

Apart from the fluid friction, other applications of systems like actuator and processes that involve mixing, cooling, and heating of fluid cause some energy losses and damping in the system

1-8 Fluid System in Term of Electrical Circuit

Usually, it is very useful to evaluate fluid system in term of electrical circuit. For example, considering fluid resistance as a relation between pressure and mass flow rate and describing the energy dissipation. Fluid capacitance can also be assumed as a relation between pressure and stored mass which illustrates the volume of potential energy.

1-9 Oil Pipeline Background

In 1859 Titusville of Pennsylvania was the first place of innovation of initial drilling company which called Colonel Drake Strike’s oil. Pennsylvania oil field recognized as main field for supplying of oil after 20 years. The first pipeline were transported the discoveries from Pennsylvania to New York City. In 1870, Rockefeller is built up his own company called standard oil company and his main purpose was to acquire kerosene refineries and transfer it through pipelines to Buffalo, Philadelphia, Cleveland, and New York. Crude oil pipelines were transporting oil from Texas, Oklahoma, and Kansas to the refineries in the East. (Ida, 1904).

In 1970 to 1990, modern pipeline spread all over the world to gather oil and gas over miles, transporting fluid carbon steel for oil recovery, transport chemicals between refineries for heating and olefins industry (Tarbell, 1904).

1-10 Crude Oil Specification

Crude oil is formed in earth layers and normally extracted with reciprocating pump, which is called pump jacks. Many kinds of fuels, such as gasoline, diesel, and kerosene are refined from crude oil, which vary in color and viscosity from site to site, but typically fall in the following ranges:

- Texas, Oklahoma

40-780 SSU (4-170 Cst) at 60°F (15°C)

34-210 SSU (2.5-45 Cst) at 100°F (38°C)

- Wyoming, Montana

75-1,200 SSU (15-250 Cst) at 60°F (15°C)

45-300 SSU (5.5-65 Cst) at 100°F (38°C)

- California

40-4,800 SSU (4-1,050 Cst) at 60°F (15°C)

34-700 SSU (2.5-150 Cst) at 100°F (38°C)

- Pennsylvania

45-200 SSU (5.5-40 Cst) at 60°F (15°C)

38-90 SSU (3.5-18 Cst) at 100°F (38°C)

Crude oil is basically hydrocarbons with some impurities in it.

Being a powerful energy source, easy to mine, stability and having high heating value, being clean and easy to burn is the most effective advantages of crude oil.

The top three oil producing countries are Saudi Arabia, Russia, and the United States. In spite of that, almost 80 per cent of the world oil is extracted from GCC which, Saudi Arabia, Iran, the UAE, Iraq, Qatar, and Kuwait stand on top. Other parts of the world, ship, refine, manufacture, and market lots of oil and waxes made from it.

1-11 Aims and Objectives

Simulating the behavior of flow rate and pressure drops in the pipelines is vastly used by different oil and gas pipeline companies. Industrially, all hydraulic calculations are carried out with software called PIPESYS which is one of the extensions of HYSYS 3.1and PIPEPHASE 9.1.

The purpose of this work is to apply the technique of lumped-distributed parameter which was introduced by Whaley and Abdul Ameer earlier as modeling and simulation of gas pipeline when losses of the system were included.

The same model is applied to our crude oil pipeline which is more complex due to its higher resistance of crude oil.

By end of this research, the reader will be able to understand the following main objectives:

1. Motor and valve description and mathematical models.

2. Modeling of finite element model when R and G are included and excluded with ten and five divisions along with simulated response of models.

3. Lumped –distributed mathematical model of the system following the aforesaid techniques, substitution of actual project’s value and simulation of the responses.

4. Comparing the response of lossy and lossless finite element model with same models of transmission line.

5. Output percentage change in volume of flow rates and the transient responses of lossy and loss less transmission lines.

5. Illustrating the response of lossy system, when approximation graph intersects the original graph in one and three locations and comparing the results.

6-extract the overall idea of most utilized way of pipeline modeling along with description.

1-12 Problem Statement

The purpose of this project is to identify and develop different methods of evaluating 10 km crude oil pipeline when all parameters of L, C, R, and G are considered as simulating the behavior of the response and demonstrating the most effective, an accurate way of computation.

1-13 Organization of the dissertation

The dissertation comprised six chapters which detail are as below:

Chapter I of the paper contains introduction and fundamental information of fluid transmission line along with flow parameters and descriptions to give overall information of fluid pipeline model system.

Chapter II brings up the history of what has been published on finite element model and variable kinds of transmission lines by accredited scholars and researchers, existing and rejected ideas to show what arguments have been established on the topic.

Chapter III and IV cover project description and mathematical derivations respectively which were an initial description of project details and actual elements and mathematical calculations of the system when two models of finite and lumped - transmission line are applied.

Chapter V represents the result of the pipeline with simulations, block diagrams, bode graphs and dynamic transient responses in order to demonstrate the behavior of each model.

Chapter VI explains the author’s conclusion and recommendation based on extracted results and graphs. Each model’s advantages and disadvantages have been discussed and finalized.

Chapter II

Literature Review

By increasing the civilization and requirements of the electricity in farther distances from power source, companies in the same field decided to locate the source of generation in long distances from consumption places and transmit power over that while losses reach to the minimum level and consumers receive almost the same power of electricity as the source generated.

This transmission, which was extracted to water as well, runs the society to tighter challenges in materials and equipment manufacture along with construction. First, an electric power transmission line with (457m) length was generated in the north of America in 1901(Drew, 2010).

2-1 Hydroelectric and Power Company's History

One of the earlier pioneers in hydroelectric was Sierra Nevada foothills of California in 1892 of which plant was completed in 1986, and run successfully. The first transformer, which was manufactured by Stanley Electrical Manufacturing Company, was applied in the same plant.

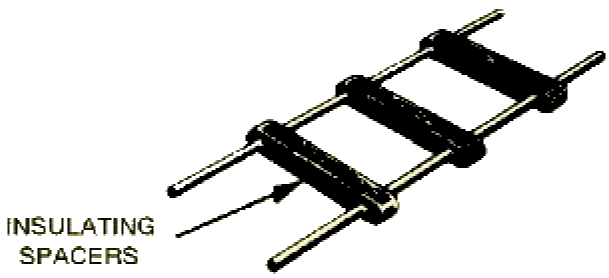
In 1898, North Yuba River Plant with (35.4 km) length utilized and ran by Nevada County Electric Power Company.

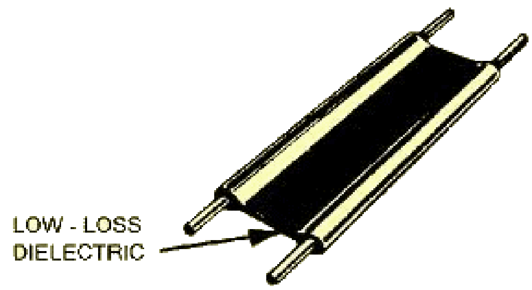
The Colgate-Oakland Transmission Line Project, which was crossed the Carquinez Straits on the San Francisco Bay was another effort in the same year by bay counties power company. Famous consultant like, William Stanley, John F. Kelley, and C. C. Chesney were hired to try operating voltage of 60 kV for the first time. To hold 10.9 metric tons of strain, large foundation concrete was built on bedrock (Drew, 2010).

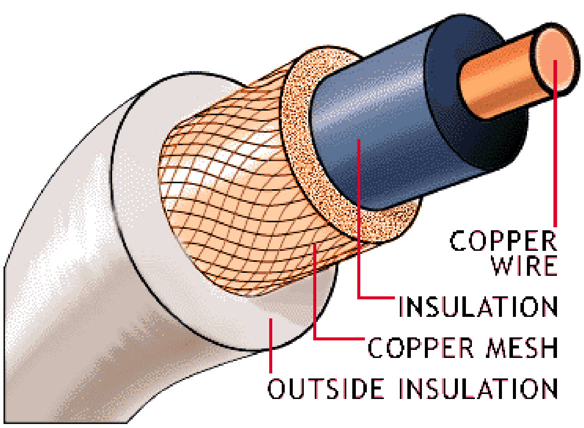
2-2 Common Types of Transmission Line

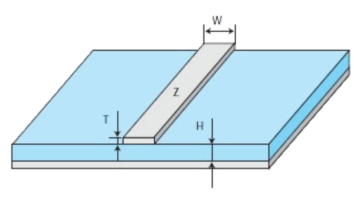
- Balanced two wire
- Co-axial Cable
- Wave guide
- Micro strip
- Fiber Optic

Balance Two Wire Lines









Co-axial Cable **Micro strip Line**

Figure (2-1) Common types of transmission lines

(http://www.daenotes.com/electronics/communication-system/transmission-line#axzz2Nmy3yNB0)

2-3 Transmission Line Matrix Model

The seventeenth century was the innovation of light and wave propagation models in which incomparable studies were conducted by Issak Newton on corpuscular model and wave model by Christian Huygens (Clayton and Paul, 2007).

In spite of the consumption of a large computer memory, the demand on transmission line model has increased enormously due to the decrease in computational costs along with the simplicity of adaption compare with other analytical means (Mariki and Yeh, 1985).

2-4 Electromagnetic Transmission Line

Studying on Electromagnetic Capability (EMC), as transmission line is another subject that began in 1950 and 1960 with frequency domain analysis of crosstalk in cables. Two conductor transmission lines as well as a high speed digital transmission line were studied by Clayton R. Paul in 2007 and he emphasized considering losses in the system (Clayton and Paul, 2007).

The new state-space transmission line model, based on electromagnetic transient has presented by using set of parallel RL branches in order to reduce the size of the model by balancing square roots algorithm and singular perturbation approximation. The propagation effect and wave travelling are considered in transmission line and discretize the line with respect to its distance (Garcia & Acha, 2008).

Applying high voltage multi circuit transmission line on the same tower can level up the capacity of transmission per area. In 2008, Feng, Wang and Zhang have proved that the effect of EHV transmission line on electromagnetic environment can be calculated by generating transmission line in variable tower modes. The authors analyzed the distribution under EHV transmission by using finite elements. Best phase line and transmission line location on the tower can be extracted (Feng, Wang and Zhang,2008).

2-5 Dual-Dimensional Transmission Line Model

Dual-Level Transmission Line Model (DLTLM) for Current flows in Metal Semiconductor Contacts was applied by Joseph M. Two dimensional current models have been shown significant improvements in the responses compared with a single or one dimension transmission

line model (Joseph, 1986).
NG analyzed the waveguide cross section by applying transmission line method of numerical analysis in two dimensions (NG, 1974).

Considering conduction term in Maxwell's equation by solving transmission line of numerical analysis was published by Akhtarzad and Johns in 1975. They examined the system with applying different inputs and enhancing the amount of losses (Akhtarzad,Johns ,1977).

Demonstration of single phase electric transmission line with finite number of ordinary differential equation was expressed by Breitholtz, Molander and Navarro (1991) that replaced TLM with cascade lumped elements, and approached stable response and known as a Method of Weighted Residual (MWR) for lossless and lossy lines (Breitholtz, Molander and Navarro,1991).

Numerical techniques for the calculation of two-dimensional scattering electromagnetic wave and using electrical network for solving electromagnetic field with applying TLM matrix model were employed by Johns and Beurle (1971) for the first time, and the results illustrated the requirement of a large storage memory. Responses were compared with the ray optic method that is not numerical, and it is not divided in to mesh. Nevertheless, the ray model consumed less computational memory, it is cannot identify the free space of scattering properties of discontinuity which run it to less accuracy (Johns and Beurle, 1971).
In the same paper, Maxwell's equation was represented by transmission line. Length of transmission lines between two nodes considered as lumped inducer and capacitor as figure (II-1) (Johns and Beurle, 1971).

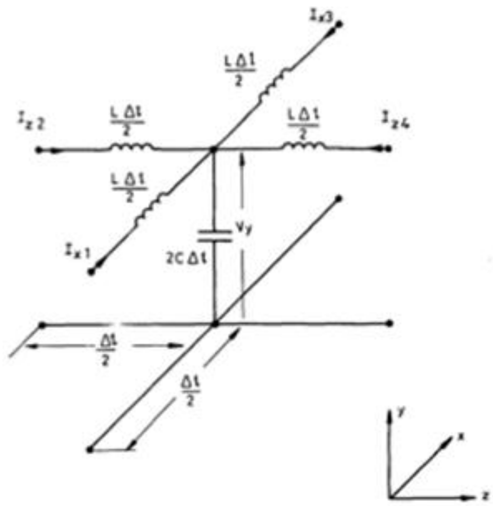


Figure (2-2) Equivalent network of transmission line junction, adapted from Johns and Beurle (1971)

Wolggran published a paper which proved that transmission line matrix method is a simpler way to demonstrate and calculate the computational model when the structure complexity is raised. Gaining the model dimension from two to three is enhancing the lines in FORTRAN from 80 to 110 which gives more complexity and consumes more memory. TLM is showing the best response of wave propagation in time domain.

The result was compared with finite element method and demonstrated more accurate responses and identified that the field function between nodes are automatically circular rather than linear. The most critical advantage of this model introduced as being practical and easy to analyze complicated structures (Wolfgran, 1985).

2-6 Three-Dimensional Transmission Line Model

The general purpose of employing three dimensional transmission line model was introduced in Nottigham University for the first time in. All the information of model starting from boundaries, strip patterns, and permeability to losses entered to program and response showed one hundred ten lines of FORTRAN. The initial model included three nodes, which were made up of six shunt and series TEM lines (Rudge , Adatia, 1975).

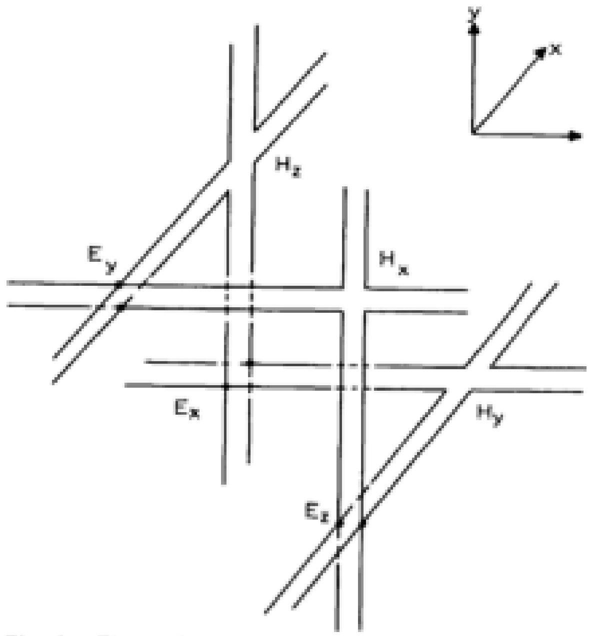


Figure (2-3) Three dimensional transmission line model, Johns and Beurle (1971)

The series and shunt nodes were constructed in the *xy, xz,* and *yz* planes, in order to have a three dimensional scattering element. As it has been shown above, each coordinate includes one shunt node and relevant crossed voltage called Ex Ey and Ez. Short circuits reflect boundary conditions. Responses simulated and showed impulses at different points in the network Akhtarzad and Johns,1974).

Johns published a paper in 1987 that demonstrated the comparison of the three dimensional transmission line with finite difference method and identified that TLM method response is more efficient and less in computational length (Johns, 1987).

The paper implies that two dimensional methods include shunt nodes connected to illustrate propagation space. In order to improve the system, shunt nodes were applied with series node as true three dimensional spaces. Hence each three-dimensional node consisted of three shunt and series nodes. As below figure E presents the shunt and series nodes.

Metallic boundaries and dielectric and magnetic materials slab's discontinuities accommodated and short- circuited length of lines were added to the model as Y_o and Z_o. G_o , Substituted as shunt node to facilitate any dielectric losses. Short circuiting and open circuiting introduced as reflecting plans which were the simulation of boundaries (Akhtarzad and Johns, 1975).

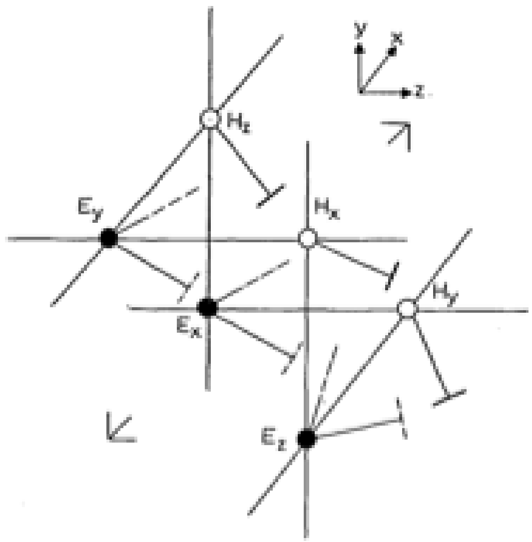


Figure (2-4) The critical rolls of losses and delay time of three dimensional circuit, Akhtarzad and Johns (1975)

Authors developed the dielectric constant of three dimensional transmission line which illustrated the prospective and performance, the critical rolls of losses and delay time of three dimensional circuits. The response showed as graphs (Darwish, Ezzeddine, 1999).

The work showed the TLM method application on propagation parameter like propagation constant, which reflected the voltage and impedance wave of integrated circuit structure .The result of this combination, demonstrated an accurate and high quality result (Tenorio and de Menezes, 2003).

2-7 Transmission Line Signal over Conducting Wires

One of the most critical subjects in electrical engineering is the transmission of signals over conducting wires. Morse invented the electric telegraph in 1838, and it came commercially to the market in 1844. Using overland and undersea conducting wires was widely used in the eighteenth centuries. The first undersea cable was connected from France to England in 1853. In

1855, a long cable telegraphic signal transmission was studied by Lord Kelvin and he made his effort to construct the formula for electric cable distributed model while the effect of magnetic field was neglected. The effect of the electric induction was assumed as capacitance and losses of system as resistance in his work (Thomson, 1855).

The effect of distance in electromagnetic theory was studied by Krishhoff in 1857. His work mainly analyzes signals, which pass through wires with finite conductivity when the effect of magnetic field is considered and defines it as the first transmission line model (Krishhoff, 1857).

Years later in 1881 -1887, the propagation of electric signal through the couples of rectilinear and parallel conducting wire was studied by Heaviside. He used the Maxwell Theory and reached to the theory that is known today (Heaviside, 1951).

2-8 Hybrid Transmission Line

TLM has been proved that it is the best numerical way to calculate Maxwell's equation of electromagnetic structures and demonstrated smaller volume of computation once improved boundaries have chosen. In this radiation structure, TLM model is combined with a multiple expansion of the radiation zone and the simulation illustrated the same result (Lorenz and Russer, 2004).

In 2001, hybrid micro strip lines modeled as transmission line which authors announced it as "Magnetic/dielectric hybrid transmission-line device", the work shows shortening of wavelength along with decreasing of ferromagnetic resonance frequency around a magnetic film (Ikeda, Sato, Ohshiro and Yamasawa, 2001) .

Multi-object optimization method employed genetic algorithm (GA) in order to extract an estimated multipoint, which was introduced by Iijima, Murakawa, Kasai, Takahashi in 2007. The advantage of this method was realizing a high accurate simulation model which was compared with an old version in terms of frequency characteristic and time domain. (MOGA) model examined on micro strip line and 2.5 more accurate response achieved. The result proved that the same method can be applied on wide range of areas, such as control, chemical, and computer engineering (Iijima, Murakawa, Kasai, and Takahashi, 2007).

2-9 Fluid Transmission Line

Fluid transmission line of small cross section describes the propagation of signals through flow which can be laminar or turbulent, incompressible or compressible. A paper which was presented by Moore developed a model which responsed to an annular transmission line compared with the same response of circular and rectangular lines. Moreover, time and frequency domain laminar mean flow extracted in the form of circular lines. Eventually, the characteristic radius was extended to turbulent mean flow. The demonstrated result showed an easy comparison with a high accuracy of response (Moore, 1977, 1978).

Ito and Ravindran presented a feasibility study on a reduced basis method in order to control the problems of fluid flow by conducting the calculation on cavity and forward-facing-step channel of viscous incompressible flow (Ito, Ravindran,1996).

The result of many surveys indicated that the flow transient is a significant Couse of corrosion cracks and erosion in the pipeline.In order to overcome the problem, Roger and Jane, introduced the optimal valve control which reduced the non-linear transient by eliminating unexpected sources and unsteady state flows. The results showed that system disturbances are affected on the condition of control stability, and at the end author suggested the adaptive control for optimal flow control (Roger and Jane, 1991).

2-10 Finite Element Model

Generalizing finite element method was introduced by Babuska for the first time. His model devided the whole field to a number of partitions when wave propagation was neglected. Authors tried to overcome different continuous problems on different parts of the system and reduce the error as much as possible (Lu and Shanker, 2007).

A paper that was published by Lu and Shanker in 2007 explored the two-dimensional holmolz system in finite element and applied various boundaries to the system. Different boundaries' results were simulated and discussed (Lu and Shanker, 2007).

The time domain finite element method for lossy transmission time was introduced by Lee , Konrad in 1993. The work illustrated the system, while numerical computation of one-dimensional boundary value of problem at each time step was considered. Single phase lossy transmission line transient analysis applied time domain finite element method (TDFE), behaved well and the result was satisfactory (Lee, Konrad, 1993).

Solving electromagnetic field with finite method to extract the distribution of it in electrical equipment was introduced by Feng, Wang and Zhang where partial differential equation were applied in each section in order to extract the approximation of each part (Feng, Wang and Zhang, 2008).

Chapter III

Project Description

Sabzab-Rey Crude Oil Pipeline Project

The main purpose of this project is to transfer our crude oil from Sabzab to Rey terminal.

The pipeline is approx. 650 km in length which includes six Pump stations and one pressure reduction.

3-1 Path characteristic

Crude oil will be transmitted from Sabzab pump station to Rey terminal via new pipelines.

• 10 Km, 30 inch pipeline from Sabzab pump station to Tang-i-Fanni pump station.

• 34.4 Km, 26 inch pipeline from Tang-i-Fanni pump station to Asar pump station.

• 76.8 Km, 26 inch pipeline from Asar pump station to Pali Baba pump station.

• 39.3 Km, 26 inch pipeline from Pali Baba pump station to Razan pump station.

• 88.9 Km, 26 inch pipeline from Razan pump station to Shazand station.

• 141.1 Km, 18 inch pipeline from Shazand station to Namak station.

• 141.2 Km, 18 inch pipeline from Namak station to Rey terminal.

ASME B 31.4 and B 31.8 introduced the Maximum allowable incidental pressure (MAIP) that occurred in a pipeline during defined frequency and time.

ASME B 31.4 and B 31.8 introduced the maximum pressure to operate under steady state condition which called Maximum allowable operating pressure (MAOP).

3-2 Soil Temperature

The temperature of area soil is in the following table range:

Minimum soil temperature	13 °C
Maximum soil temperature	23 °C

10 Km of 30 inch pipeline from Sabzab to Tang-i-Fanni pump station is considered. Specific crude oil with a weight of 0.8876 grams, density of 886.6 kg/m^3 and viscosity of 29.13 cst with 10 Celsius temperature run through the pipe. Mathematical calculation is driven, values are substituted and the result is presented to demonstrate the percentage of flow rate along the length in second.

Chapter IV

Mathematical Derivation

To drive the mathematical computation of the system, the specification below should be considered:

A) The flow of a fluid is considered in a constant-area, rigid-walled pipe.

B) Variables of primary interest are, average fluid pressure *h* and the volume flow rate *q*.

C) The average flow velocity V_e is defined as $\frac{q}{A}$, where *A* is the pipe cross-sectional area.

D) Fluid is assumed to be incompressible, steady, laminar, and one dimensional.

E) While the actual fluid pressure and velocity vary from point to point over the flow cross section in a real fluid flow, we assume a so-called one-dimensional flow model in which the velocity and pressure are uniform over the area.

4-1 Pump specification and mathematical model

Hydraulic actuations devices like pumps work either linear or rotary which is related to piston or motor movement respectfully.

The pump–controlled system and motor movement consists of pump which supplies the fluid to an actuation device. Speed and pressure of the fluid can be changed by pump stock. Supplying the power is usually a constant pressure type. Two basic configuration of pump is consisting of constant delivery pump with a relief valve to direct the pressure and variable delivery pump with stroke control to guide and regulate the pressure (Juma, 1995).

Handling and transferring of oil is a critical issue nowadays. Due to challenging responsibility of pumps for heating, transporting oil variant kinds of pumps entered to refinery and petrochemical fields, which rotary pumps found an excellent means loading/unloading, transferring, and circulating fuels. Some examples are as follows:

- Diesel Fuel
- Heavy Oils
- Crude Oil

- Gasoline
- Kerosene
- Jet Fuel
- LP Gas

Applying the pump in different industries and applications increased the production and fabrication of multi-operational pumps. At the same time to operate variance types easily and increasing the life of pumps, common guidelines are provided.

In order to transport the high viscosity fluids such as crude oil, rotary pumps are suited. Cast Iron rotary pumps are also used for high pressure pipeline sampling applications. In overall pump construction is mainly based on its applications and viscosity of fluid which passes thought it in the process. To filter the crude oil and separate dirt, sand and other particulate of oil, pumps are supplied with specific parts to refine the oil and prevent the pump from damage.

TSP double-suction, twin-screw pump is the most versatile of all viscous liquid pumps. With the inherent characteristics of positive displacement, pulse-free flow, and high-suction lift/self-priming capabilities, it delivers smooth and constant flow across the 10,000 meters of pipe. Schematic diagram of pump is as figure (4-1):

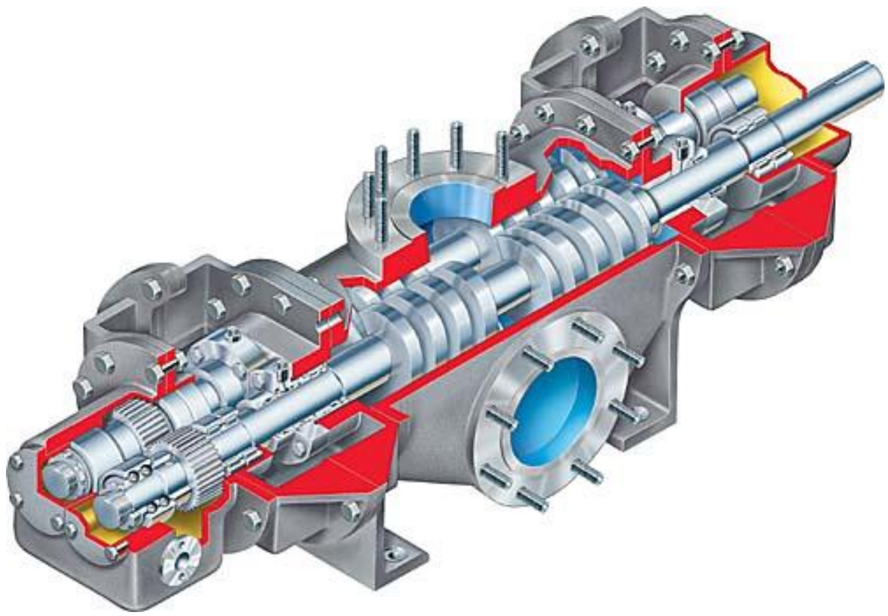


Figure (4-1) Schematic diagram of TSP double-suction, twin-screw pump

(http://www.flowserve.com/Products/Pumps/Industries/Oil-and-Gas-Upstream-and-Pipeline/Crude-and-CO2-Pipeline/TSP-DoubleSuction,-TwinScrew-Pum,en_US)

The mathematical calculation of the pump which was modeled as lumped element is presented as below:

$$T(s) = K_m I_f(s) \qquad 4\text{-}1\text{-}1$$

$$I_f(s) = \frac{V\ (s)}{L_f s + R_f} \qquad 4\text{-}1\text{-}2$$

$$T(s) = \frac{K_m V(s)}{L_f s + R_f} \qquad 4\text{-}1\text{-}3$$

$$T(s) = \frac{K_m / R_f}{\tau s + 1} V(s) \qquad 4\text{-}1\text{-}4$$

4-2 Valve mathematical model (Terminal load calculation)

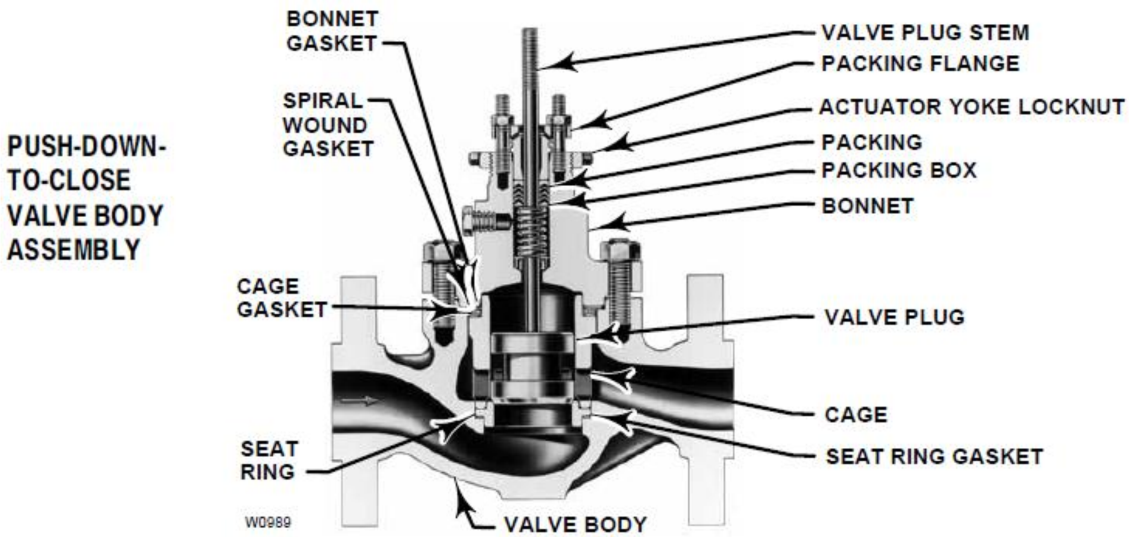


Figure (4-2) Major components of typical control valve assemblies

Emerson Process Management. "Control Valve Handbook," (4th ed), U.S.A.:Fisher Controls International LLC. (2005).

Manufacturing, refineries and in overall all kind of process plants consist of many control loops which are designed to manage different process variables such as temperature, pressure and flow level. Each process might face variant kind of disturbance that effects on the performance of the system. Controllers are designed for each process to collect all the information of the system and decide the action that should take place to get the process variable back to where it should be after a disturbance occurs.

Control valves are introduced to the industry to control the element of process when all the calculations and measurement is completed. Control valves guide a flow and compensate the load disturbance. Their assembly consists of valve body, actuators, transducer, pressure regulator and switches. Control Valve consists of resistance which its relation with pressure and flow rate can be illustrated as:

$$h_2 = R_v q_2 \qquad \text{4-2-1}$$

4-3 Finite Element Model without Losses

Basic concept is discretization technique in structural mechanic which introduced sub-division of the mathematical model into non-overlapping components of the system.

Obtained discrete model will be an approximation of response of mathematical model which was achieved by the collection of all elements.

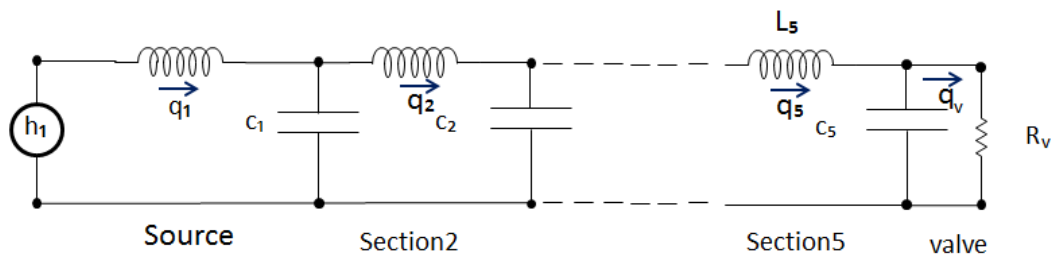


Figure (4-3) Lossless finite element model with five divisions

$$h_1 = L_1 s q_1 + \frac{1}{C_1 s}(q_1 - q_2) \qquad \text{4-3-1}$$

$$0 = \frac{1}{C_1 s}(q_2 - q_1) + L_2 s q_2 + \frac{1}{C_2 s}(q_2 - q_3) \qquad \text{4-3-2}$$

$$0 = \frac{1}{C_2 s}(q_3 - q_2) + L_3 s q_3 + \frac{1}{C_3 s}(q_3 - q_4) \qquad \text{4-3-3}$$

$$0 = \frac{1}{C_3 s}(q_4 - q_3) + L_4 s q_4 + \frac{1}{C_4 s}(q_4 - q_5) \qquad \text{4- 3-4}$$

$$0 = \frac{1}{C_4 s}(q_5 - q_4) + L_5 s q_5 + \frac{1}{C_5 s}(q_5 - q_v) \qquad \text{4-3-5}$$

$$0 = \frac{1}{C_5 s}(q_v - q_5) + R_v q_v \qquad \text{4-3-6}$$

$$\begin{bmatrix} h_1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = 0 \begin{bmatrix} L_1 s + \frac{1}{C_1 s} & -\frac{1}{C_1 s} & 0 & 0 & 0 & 0 \\ -\frac{1}{C_1 s} & L_2 s + \frac{1}{C_1 s} + \frac{1}{C_2 s} & -\frac{1}{C_2 s} & 0 & 0 & 0 \\ 0 & -\frac{1}{C_2 s} & L_3 s + \frac{1}{C_2 s} + \frac{1}{C_3 s} & -\frac{1}{C_3 s} & 0 & 0 \\ 0 & 0 & -\frac{1}{C_3 s} & L_4 s + \frac{1}{C_3 s} + \frac{1}{C_4 s} & -\frac{1}{C_4 s} & 0 \\ 0 & 0 & 0 & -\frac{1}{C_4 s} & L_5 s + \frac{1}{C_4 s} + \frac{1}{C_5 s} & -\frac{1}{C_5 s} \\ 0 & 0 & 0 & 0 & -\frac{1}{C_5 s} & -\frac{1}{C_5 s} + R_v \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \\ q_v \end{bmatrix} \qquad \text{4-3-7}$$

$$[h_1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]^T = G(s)[q_1 \quad q_2 \quad q_3 \quad q_4 \quad q_5 \quad q_v]^T \qquad \text{4-3-8}$$

$$[q_1 \quad q_2 \quad q_3 \quad q_4 \quad q_5 \quad q_v]^T = G(s)^{-1}[h_1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]^T \qquad \text{4-3-9}$$

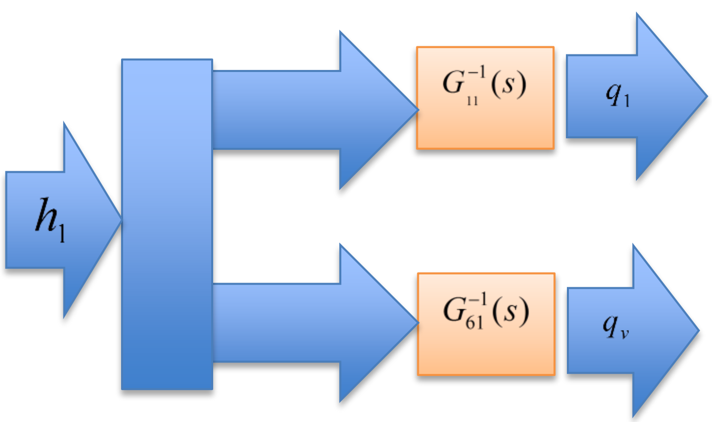


Figure (4-4) parallel model of finite element

4-4 Finite element model with losses

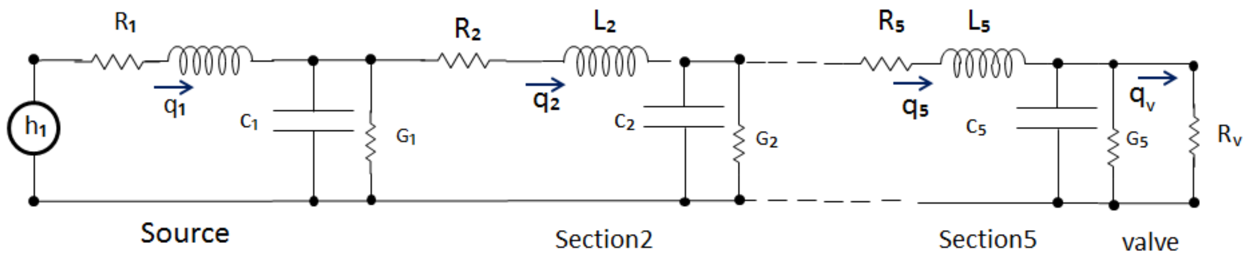


Figure (4-5) Lossly finite element model with 5 divisions

Considering L and R as Z_R and G and C as Z_G in each section can be presented as follow:

$$Z_R = Ls + R \qquad 4\text{-}4\text{-}1$$

$$Z_G = \frac{G}{CGs+1} \qquad 4\text{-}4\text{-}2$$

Since Z_R and Z_G are in parallel, it can be rewritten as:

$$M = \frac{Z_G Z_R}{Z_R + Z_G} \qquad 4\text{-}4\text{-}3$$

$$M = \frac{\left(\frac{G}{CGs+1}\right)(Ls+R)}{Ls+R+\frac{G}{CGs+1}} \qquad 4\text{-}4\text{-}4$$

By Substituting the achieved M in a derived five division's pipeline equations, lossy finite element matrix can be constructed as:

$$\left[\begin{matrix} \dfrac{(\frac{G_1}{C_1G_1s+1})(L_1s+R_1)}{L_1s+R_1+\frac{G_1}{C_1G_1s+1}} & -\dfrac{G_1}{C_1G_1s+1} & 0 \\ -\dfrac{G_1}{C_1G_1s+1} & \dfrac{(\frac{G_2}{C_2G_2s+1})(L_2s+R_2)}{L_2s+R_2+\frac{G_2}{C_2G_2s+1}}+\dfrac{G_1}{C_1G_1s+1} & -\dfrac{G_2}{C_2G_2s+1} \\ 0 & -\dfrac{G_2}{C_2G_2s+1} & \dfrac{(\frac{G_3}{C_3G_3s+1})(L_3s+R_3)}{L_3s+R_3+\frac{G_3}{C_3G_3s+1}}+\dfrac{G_2}{C_2G_2s+1} \\ 0 & 0 & -\dfrac{G_3}{C_3G_3s+1} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix}\right.$$

$$\left.\begin{matrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ -\dfrac{G_3}{C_3G_3s+1} & 0 & 0 \\ \dfrac{(\frac{G_4}{C_4G_4s+1})(L_4s+R_4)}{L_4s+R_4+\frac{G_4}{C_4G_4s+1}}+\dfrac{G_3}{C_3G_3s+1} & -\dfrac{G_4}{C_4G_4s+1} & 0 \\ -\dfrac{G_4}{C_4G_4s+1} & \dfrac{(\frac{G_5}{C_5G_5s+1})(L_5s+R_5)}{L_5s+R_5+\frac{G_5}{C_5G_5s+1}}+\dfrac{G_4}{C_4G_4s+1} & -\dfrac{G_5}{C_5G_5s+1} \\ 0 & -\dfrac{G_5}{C_5G_5s+1} & R_v+\dfrac{G_5}{C_5G_5s+1} \end{matrix}\right] \tag{4-4-5}$$

As figure (4-4-4), two values of $G_{11}^{-1}(s)$ and $G_{61}^{-1}(s)$ extract and substitute in Matlab relevant block diagram. Transient response of the system demonstrated in chapter V.

4-5 Distributed mathematical model without losses

Lumped element's Signal transmission assumed to be without any delay which runs the system to less accuracy and unreliability. Distributing the parameter along the system in long transmission line and considering all dynamic interconnection of the elements is more applicable and depend on solution of PDE (Whaley and Abdul Ameer, 2010).

Generalizing the concept to all mechanical and electrical long transmission line has enhanced the reliability of result and simplified the calculation.

Presenting 10 km pipeline in circuit format which introduced by Abdul Ameer and Whalley for lossless system which include L as inductance and C as capacitance and substituting the pipeline parameter is as figure (4-6):

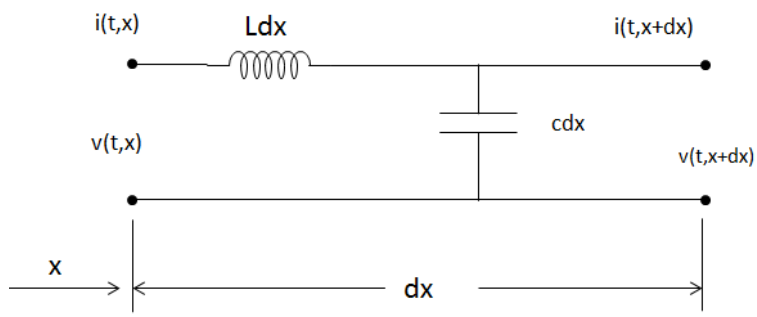


Figure (4-6) Lossless circuit distributed parameter model

$$v(t,x+dx)-v(t,x)=-L\frac{\partial i(t,x+dx)}{\partial t} \qquad \text{4-5-1}$$

$$i(t,x+dx)-i(t,x)=-C\frac{\partial v(t,x+dx)}{\partial t} \qquad \text{4-5-2}$$

Similarly pipeline L and C display as (4-5-3) and (4-5-4)

$$h(t,x+dx)-h(t,x)=-L\frac{\partial q(t,x+dx)}{\partial t} \qquad \text{4-5-3}$$

$$q(t,x+dx)-q(t,x)=-C\frac{\partial h(t,x+dx)}{\partial t} \qquad \text{4-5-4}$$

Tacking the limit of $dx \rightarrow 0$

$$\frac{\partial h(t,x)}{\partial x} = -L\frac{\partial q(t,x)}{\partial t} \quad 4\text{-}5\text{-}5$$

$$\frac{\partial q(t,x)}{\partial x} = -C\frac{\partial h(t,x)}{\partial t} \quad 4\text{-}5\text{-}6$$

Converting (4-5-5) and (4-5-6) to Laplace transformation with respect to time when initial condition is zero, the equations are revised as:

$$\frac{dh(s,x)}{dx} = -Lsq(s,x) \quad 4\text{-}5\text{-}7$$

$$\frac{dq(s,x)}{dx} = -Csh(s,x) \quad 4\text{-}5\text{-}8$$

Applying general solution of $h(s,x)$and $q(s,x)$ are:

$$h(s,x) = A\cosh\Gamma(s)x + N\sinh\Gamma(s)x \quad 4\text{-}5\text{-}9$$

$$q(s,x) = M\sinh\Gamma(s)x + D\cosh\Gamma(s)x \quad 4\text{-}5\text{-}10$$

Accordingly differentiating the general solution $h(s,x)$and $q(s,x)$ of equation (5-5-9) and (5-5-10) and equating it to equation (5-5-7) and (5-5-8), can be expressed as below:

$$\frac{dh}{dx}(s,x) = -Lsq(s,x) = A\Gamma(s)\sinh\Gamma(s)x + N\Gamma(s)\cosh\Gamma(s)x \quad 4\text{-}5\text{-}11$$

$$\frac{dq}{dx}(s,x) = -Csh(s,x) = M\Gamma(s)\cosh\Gamma(s)x + D\Gamma(s)\sinh\Gamma(s)x \quad 4\text{-}5\text{-}12$$

Equation (4-5-11) when $x = 0$ become

$$-Lsq(s,0) = N\Gamma(s) \quad 4\text{-}5\text{-}13$$

So that

$$N = -\frac{L(s)}{\Gamma(s)}q(s,0) \quad 4\text{-}5\text{-}14$$

Since $\Gamma = \sqrt{LC}$ 4-5-15

$$N = -\sqrt{\frac{L}{C}}q(s,0) \quad \text{4-5-16}$$

Also from equation (4-5-12)

$$-Csh(s,0) = M\Gamma(s) \quad \text{4-5-17}$$

$$M = -\frac{C(s)}{\Gamma(s)}h(s,0) == -\sqrt{\frac{C}{L}}h(s,0) \quad \text{4-5-18}$$

Assuming characteristic impedance and propagation as below:

$$\zeta = \sqrt{\frac{L}{C}}$$

4-5-19

$$\Gamma(s) = \sqrt{LC} \quad \text{4-5-20}$$

$$N = -\zeta q(s,0) \quad \text{and} \quad M = -\zeta^{-1}h(s,0) \quad \text{4-5-21}$$

Hence equation (5-9) and (5-10) become

$$h(s,x) = \cosh\Gamma(s)xh(s,0) - \zeta\sinh\Gamma(s)xq(s,0) \quad \text{4-5-22}$$

$$q(s,x) = -\zeta^{-1}\sinh\Gamma(s)xh(s,0) + \cosh\Gamma(s)xq(s,0) \quad \text{4-5-23}$$

At distance l along the pipe

$$\begin{bmatrix} h(s,l) \\ q(s,l) \end{bmatrix} = \begin{bmatrix} \cosh\Gamma(s)l & -\zeta\sinh\Gamma(s)l \\ -\zeta^{-1}\sinh\Gamma(s)l & \cosh\Gamma(s)l \end{bmatrix} \begin{bmatrix} h(s,0) \\ q(s,0) \end{bmatrix} \quad \text{4-5-24}$$

Rearrange equation as follow

$$\begin{bmatrix} h(s,l) \\ q(s,l) \end{bmatrix} = \begin{bmatrix} \cosh\Gamma(s)lh(s,0) & -\zeta\sinh\Gamma(s)lq(s,0) \\ -\zeta^{-1}\sinh\Gamma(s)lh(s,0) & \cosh\Gamma(s)lq(s,0) \end{bmatrix}$$

4-5-25

$$h(s,l) - \cosh \Gamma l h(s,0) = -\zeta \sinh \Gamma l q(s,0)$$ 4-5-26

$$\zeta^{-1} \sinh \Gamma l h(s,0) = \cosh \Gamma l q(s,0) - q(s,l)$$ 4-5-27

$$\begin{bmatrix} 1 & -\cosh \Gamma l \\ 0 & \zeta^{-1} \sinh \Gamma l \end{bmatrix} \begin{bmatrix} h(s,l) \\ h(s,0) \end{bmatrix} = \begin{bmatrix} 0 & -\zeta \sinh \Gamma l \\ -1 & \cosh \Gamma l \end{bmatrix} \begin{bmatrix} q(s,l) \\ q(s,0) \end{bmatrix}$$ 4-5-28

$$\begin{bmatrix} h(s,l) \\ h(s,0) \end{bmatrix} = \frac{\begin{bmatrix} \zeta^{-1} \sinh \Gamma l & \cosh \Gamma l \\ 0 & 1 \end{bmatrix}}{\zeta^{-1} \sinh \Gamma l} \begin{bmatrix} 0 & -\zeta \sinh \Gamma l \\ -1 & \cosh \Gamma l \end{bmatrix} \begin{bmatrix} q(s,l) \\ q(s,0) \end{bmatrix}$$ 4-5-29

$$\begin{bmatrix} h(s,l) \\ h(s,0) \end{bmatrix} = \frac{\begin{bmatrix} \cosh \Gamma l & -\sinh^2 \Gamma l + \cosh^2 \Gamma l \\ -1 & \cosh \Gamma l \end{bmatrix}}{\zeta^{-1} \sinh \Gamma l} \begin{bmatrix} q(s,l) \\ q(s,0) \end{bmatrix}$$ 4-5-30

Equation (4-30) can be arranged in impedance form as:

$$\begin{bmatrix} h(s,l) \\ h(s,0) \end{bmatrix} = \begin{bmatrix} -\zeta ctnh \Gamma(s) l & \zeta \csc h \Gamma l \\ -\zeta \csc h \Gamma\ (s) l & \zeta ctnh \Gamma l \end{bmatrix} \begin{bmatrix} q(s,l) \\ q(s,0) \end{bmatrix}$$ 4-5-31

Where: $ctnh \Gamma(s) l = (e^{2\Gamma l} + 1)/(e^{2\Gamma l} - 1) = W$ 4-5-32

And $\csc h \Gamma(s) l = (ctnh^2 \Gamma(s) l - 1)^{\frac{1}{2}} = \dfrac{2e^{l\Gamma(s)}}{e^{2l\Gamma(s)} - 1} = (W^2 - 1)^{\frac{1}{2}}$ 4-5-33

$$h(s,0) = h_1(s), h(s,l) = h_2(s)$$ 4-5-34

$q(s,0) = q_1(s)$ and $q(s,l) = q_2(s)$ 4-5-35

$$\begin{bmatrix} h_2(s) \\ h_1(s) \end{bmatrix} = \begin{bmatrix} -\zeta W & \zeta\ (W^2(s) - 1)^{\frac{1}{2}} \\ -\zeta (W^2(s) - 1)^{\frac{1}{2}} & \zeta W(s) \end{bmatrix} \begin{bmatrix} q_2(s) \\ q_1(s) \end{bmatrix}$$ 4-5-36

$$\begin{bmatrix} h_1(s) \\ h_2(s) \end{bmatrix} = \begin{bmatrix} \zeta\ W & -\zeta(W^2(s)-1)^{\frac{1}{2}} \\ \zeta(W^2(s)-1)^{\frac{1}{2}} & -\zeta W(s) \end{bmatrix} \begin{bmatrix} q_1(s) \\ q_2(s) \end{bmatrix} \qquad \text{4-5-37}$$

4-6 Lumped-Distributed Parameter Mathematical Model when R and G are not included

By including the effect of valve resistance on the system as lumped parameter and substituting equation (4-2-1) in the mathematical calculation of distributed parameter where h_2 assumed as zero due to closure situation of valve, equation (4-5-37) represent as (4-6-1).

$$\begin{bmatrix} h_1(s) \\ 0+R_v \end{bmatrix} = \begin{bmatrix} \zeta W & -\zeta(W^2(s)-1)^{\frac{1}{2}} \\ \zeta(W^2(s)-1)^{\frac{1}{2}} & -\zeta W(s) \end{bmatrix} \begin{bmatrix} q_1(s) \\ q_2(s) \end{bmatrix} \qquad \text{4-6-1}$$

$$\begin{bmatrix} h_1(s) \\ 0 \end{bmatrix} = \begin{bmatrix} \zeta\ W & -\zeta(W^2(s)-1)^{\frac{1}{2}} \\ \zeta(W^2(s)-1)^{\frac{1}{2}} & -\zeta W(s)-(R_v) \end{bmatrix} \begin{bmatrix} q_1(s) \\ q_2(s) \end{bmatrix} \qquad \text{4-6-2}$$

$$\begin{bmatrix} q_1(s) \\ q_2(s) \end{bmatrix} = \frac{\begin{bmatrix} -\zeta W(s)-(+R_v) \\ -\zeta(W^2(s)-1)^{\frac{1}{2}} \end{bmatrix}}{-\zeta W(s)(R_v)-\zeta^2} h_1(s) \qquad \text{4-6-3}$$

$$\begin{bmatrix} q_1(s) \\ q_2(s) \end{bmatrix} = \frac{\begin{bmatrix} \zeta W(s)+R_v \\ \zeta(W^2(s)-1)^{\frac{1}{2}} \end{bmatrix}}{\zeta W(s)(R_v)+\zeta^2} h_1(s) \qquad \text{4-6-4}$$

In order to display the response of system efficiently, overall model is constructed in Matlab as function’s block diagrams. Achieved plots can be studied accordingly.

To simulate equation (4-6-4) in Matlab, nominator and denominator is divided to highest order polynomial, which construct the final block diagram as figure (4-7)

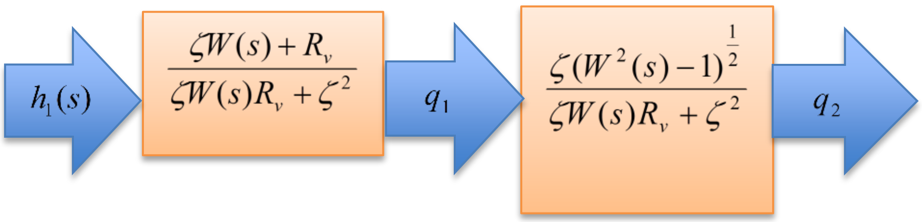


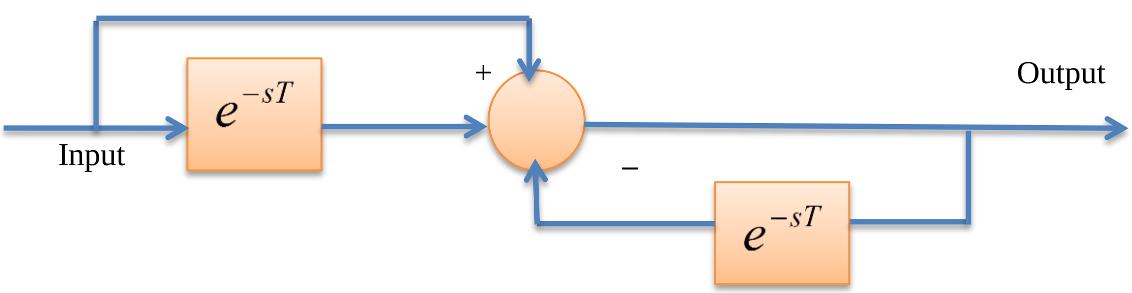
Figure (4-7) Series model topology for lossless long pipe line

Which subassembly are as equation (4-6-5) and (4-6-6), that introduced by Abdul Ameer and Walley (2010).

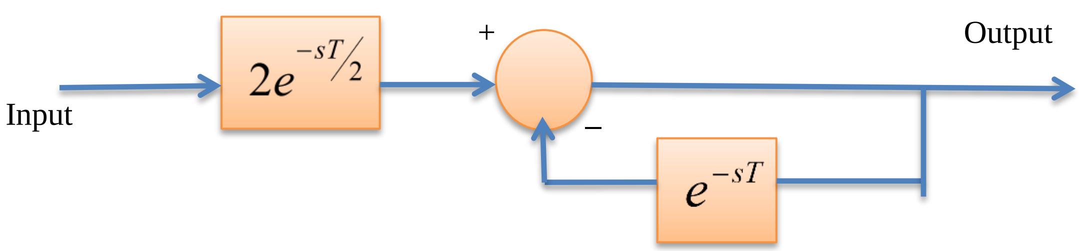
$$W(s)=\frac{1+e^{-2l\Gamma}}{1-e^{-2l\Gamma}}=\frac{1+e^{-sT}}{1-e^{-sT}} \qquad \text{4-6-5}$$

$$(W^2(s)-1)^{\frac{1}{2}}=\frac{2e^{-sT/2}}{1-e^{-sT}} \qquad \text{4-6-6}$$

And where, $W(s)$ demonstration is as below:



And $(W^2(s)-1)^{\frac{1}{2}}$ as following



4-7 Distributed Mathematical Model with Losses

According to figure (4-8) L and C are introduced as long transmission line inductance and capacitance and R and G as system resistance and shunt resistance respectively.

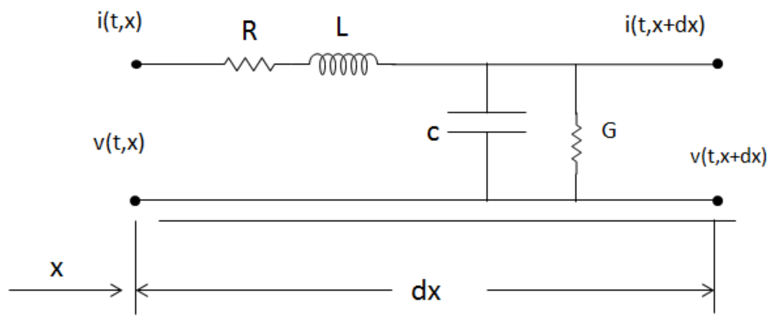


Figure (4-8) Lossy circuit distributed parameter model

$$v(t,x+dx)-v(t,x)=-[L\frac{\partial i(t,x+dx}{\partial t}+Ri]dx \qquad \text{4-7-1}$$

$$i(t,x+dx)-i(t,x)=-[C\frac{\partial i(t,x+dx}{\partial t}+Gi]dx \qquad \text{4-7-2}$$

Taking the limit $dx \to 0$, Equation (4-7-1) and (4-7-2) becomes:

$$\frac{\partial v(t,x)}{\partial x}=-[L\frac{\partial}{\partial t}+R]i(t,x) \qquad \text{4-7-3}$$

$$\frac{\partial i(t,x)}{\partial x}=-[C\frac{\partial}{\partial t}+G]v(t,x) \qquad \text{4-7-4}$$

Substituting Hybrid pipeline system's parameter in above by considering R as fluid friction resistance and G, as fluid shunt resistance, are extracted as:

$$\frac{\partial H}{\partial x}(x,t)=-[L\frac{\partial}{\partial t}+R]Q(x,t) \qquad \text{4-7-5}$$

And

$$\frac{\partial Q}{\partial x}(x,t) = -[C\frac{\partial}{\partial t} + G]H(x,t) \qquad \text{4-7-6}$$

Where

$$G = \frac{g}{B^2}Q \qquad \text{4-7-7}$$

$$C = \frac{gA}{B^2} \qquad \text{4-7-8}$$

$$L = \frac{1}{gB} \qquad \text{4-7-9}$$

Fluid friction causes pressure head loss in pipeline which dissipates energy and could be separated into two types of steady state and unsteady damping. In order to avoid complexity in mathematical calculation, both R and G are considered as constant.

Back to equation (4-7-5) and (4-7-6), L reflecting the equivalent fluid inductance per unit length and R exhibiting constant fluid resistance, below equations would be expressed:

$$\frac{\partial h(t,x)}{\partial x} = -L\frac{\partial q(t,x)}{\partial t} + Rq(t,x) \qquad \text{4-7-10}$$

$$\frac{\partial q(t,x)}{\partial x} = -C\frac{\partial h(t,x)}{\partial t} + Gh(t,x) \qquad \text{4-7-11}$$

In a normal differential equation, Following Laplace transformation, with respect to time, with zero initial conditions will be as:

$$\frac{dh(s,x)}{dx} = -[Ls + R]q(s,x) \qquad \text{4-7-12}$$

$$\frac{dq(s,x)}{dx} = -[Cs+G]h(s,x) \qquad \text{4- 7-13}$$

Accordingly the general solution $h(s,x)$ and $q(s,x)$ of equation (4-5-9) and (4-5-10) and equating it to equation (4-7-12) and (4-7-13), it can be expressed as below:

$$\frac{dh}{dx}(s,x) = -[Lsq(s,x)+R(s,x)] = A\Gamma(s)\sinh\Gamma(s)x + N\Gamma(s)\cosh\Gamma(s)x \qquad \text{4-7-14}$$

$$\frac{dq}{dx}(s,x) = -[Csh(s,x)+Gh(s,x)] = M\Gamma(s)\cosh\Gamma(s)x + D\Gamma(s)\sinh\Gamma(s)x \qquad \text{4-7-15}$$

Equation (4-7-14) when x=0 revised as:

$$-[Lsq(s,0)+Rq(s,0)] = N\Gamma(s) \qquad \text{4-7-16}$$

So that

$$N = -[\frac{L(s)+R}{\Gamma(s)}]q(s,0) = -[\frac{Ls+R}{\sqrt{(Ls+R)(Cs+G)}}]q(s,0) = -\sqrt{\frac{Ls+R}{Cs+G}}q(s,0) \qquad \text{4-7-17}$$

Accordingly equation (4-7-15)

$$-[Csh(s,0)+Gh(s,0)] = M\Gamma(s) \qquad \text{4-7-18}$$

$$M = -[\frac{C(s)+G}{\Gamma(s)}]h(s,0) = -[\frac{Cs+G}{\sqrt{(Ls+R)(Cs+G)}}]h(s,0) = -[\sqrt{\frac{Cs+G}{Ls+R}}]h(s,0)] \qquad \text{4-7-19}$$

If the characteristics impedance and propagation is defined as:

$$\zeta = \sqrt{\frac{Ls+R}{Cs+G}} = \sqrt{\frac{R(\frac{Ls}{R}+1)}{G(\frac{Cs}{G}+1)}} = \sqrt{\frac{R}{G}}\sqrt{\frac{\frac{Ls}{R}+1}{\frac{Cs}{G}+1}} \qquad \text{4-7-20}$$

And

$$\Gamma(s)=\sqrt{(Ls+R)(Cs+G)}=\sqrt{RG}\sqrt{(\frac{Ls}{R}+1)(\frac{Cs}{G}+1)} \qquad 4\text{-}7\text{-}21$$

$$\begin{bmatrix} h_1(s) \\ h_2(s) \end{bmatrix}=\begin{bmatrix} \zeta\, W & -\zeta(W^2(s)-1)^{\frac{1}{2}} \\ \zeta(W^2(s)-1)^{\frac{1}{2}} & -\zeta W(s) \end{bmatrix}\begin{bmatrix} q_1(s) \\ q_2(s) \end{bmatrix} \qquad 4\text{-}7\text{-}22$$

4-8 Lumped- Distributed Parameter Mathematical Model when R and G are Included

Applying the effect of control valve as lumped element by substituting R_v and considering $h_2 = 0$ as final head pressure which is due to closure situation of valve, equation (4-7-22) is rewritten as below:

$$\begin{bmatrix} q_1(s) \\ q_2(s) \end{bmatrix}=\frac{\begin{bmatrix} \zeta W(s)+R_v \\ \zeta(W^2(s)-1)^{\frac{1}{2}} \end{bmatrix}}{\zeta W(s)(R_v)+\zeta^2}h_1(s) \qquad 4\text{- }8\text{-}1$$

Series topology and subassembly block diagram's presentation are shown in Figures (4-6-1) and (4-6-2) and (4-6-3).

Since calculating distributed parameter in fluid pipeline like L and R are function of time and unsolvable in s domain, a new method which has suggested by Abdul Ameer (2012), will be used when :

$$\frac{1}{G_j}\rangle R_j\,, L_j\rangle\rangle C_j \qquad 4\text{-}8\text{-}2$$

Then

$$(\frac{C_j s}{G_j}+1)\frac{\prod_{k=1}^{L}(T_{jk}+1)^2}{\prod_{k=1}^{L}(\tau_{jk}+1)^2}\cong(\frac{L_j s}{R_j}+1) \qquad 4\text{-}8\text{-}3$$

From the equation (4-7-22) and (4-8-3)

$$\Gamma = \sqrt{RG}\left((\frac{Ls}{R}+1)(\frac{Cs}{G}+1)\right)^{\frac{1}{2}} = \alpha\left(\frac{(T_1 s+1)(T_2 s+1)}{(\tau_1 s+1)(\tau_2 s+1)}(\frac{Cs}{G}+1)\right) \quad 4\text{-}8\text{-}4$$

Where

$$\alpha = \sqrt{RG} \quad 4\text{-}8\text{-}5$$

Substitution of (4-8-3) in impedance equation (4-7-20), its expressed as :

$$\zeta = \sqrt{\frac{Ls+R}{Cs+G}} = \sqrt{\frac{R(\frac{Ls}{R}+1)}{G(\frac{Cs}{G}+1)}}\sqrt{\frac{R}{G}}\sqrt{\frac{\frac{Ls}{R}+1}{\frac{Cs}{G}+1}} = \bar{a}\left(\frac{\frac{(T_1 s+1)(T_2 s+1)}{(\tau_1 s+1)(\tau_2 s+1)}(\frac{Cs}{G}+1)}{\frac{Cs}{G}+1}\right) \quad 4\text{-}8\text{-}6$$

$$\zeta = \bar{a}\frac{(T_1 s+1)(T_2 s+1)}{(\tau_1 s+1)(\tau_2 s+1)} \quad 4\text{-}8\text{-}7$$

Where

$$\bar{\alpha} = \sqrt{\frac{R}{G}} \quad 4\text{-}8\text{-}8$$

$$W = (1+e^{-2\Gamma l})/(1-e^{-2\Gamma l}) = (1+e^{-2l\sqrt{RG}\chi(s)})/(1-e^{-2l\sqrt{RG}\chi(s)}) \quad 4\text{-}8\text{-}9$$

$$(W^2-1)^{\frac{1}{2}} = 2e^{-l\Gamma(s)}/(1-e^{-2l\,\Gamma(s)}) = 2e^{-l\sqrt{RG}\chi(s)}/(1-e^{-2l\sqrt{RG}\chi(s)}) \quad 4\text{-}8\text{-}10$$

Where

$$\chi(s) = \frac{(T_1 s+1)(T_2 s+1)}{(\tau_1 s+1)(\tau_2 s+1)}(\frac{C_0 s}{G_0}+1) \quad 4\text{-}8\text{-}11$$

And

$$\chi(s) \cong as+b \quad 4\text{-}8\text{-}12$$

$$a = [\frac{C}{G} + (T_1 + T_2) - (\tau_1 + \tau_2)] \qquad 4\text{-}8\text{-}13$$

Hence, equation (4-8-9) and (4-8-10) can be rewrite as below:

$$W = (1 + e^{-2l\alpha(a+b)})/(1 - e^{-2l\alpha(a+b)}) \qquad 4\text{-}8\text{-}14$$

$$(W^2 - 1)^{\frac{1}{2}} = 2e^{-l\alpha(a+b)}/(1 - e^{-2l\alpha(a+b)}) \qquad 4\text{-}8\text{-}15$$

Chapter V

Result Simulation and Methodology

Simulation is a decision analysis and support tool. It is allowed the user to integrate the framework of different component of the system, in order to understand their interconnection properly (Saxena, 2011).

MATLAB is high-performance software which can be used to compute, program and simulate. In addition to initial capability, it can apply for data acquisition, modeling, prototyping and building interface.Textbooks which call M-file help the user to apply MATLAB for variant kind of applications (Garham, 2009).

The time response represents how the state of a dynamic system changes in the time when it is subjected to a particular input. Since the systems which will drive are consisting of differential equations, some integration must be performed in order to determine the time response of the system. MATLAB provides many useful resources for calculating time responses for many types of inputs, the time response of a linear dynamic system consists of the sum of the transient response which depends on the initial conditions, the steady-state response and the system input.

The settling time, is the time required for the system output to fall within a certain percentage of the steady state value for a step input or equivalently to decrease to a certain percentage of the initial value for an impulse input.

The most important aspect of control system's behavior is its response to disturbance. Disturbances are all inputs which affect the system that sometimes are not measurable and can be identified by variation in process output signals.

Applying different kind of controller is a way to maintain the response of system within desired output. The effect of disturbance is introduced in term of steady state, which is demonstration of change of output to the change of disturbance (Gardner and Shearer, 2007).

Despite this fact that extensive research has been carried out on transmission lines models, subjected to including systems losses, no proper way of calculation and accurate computation were strongly defined till 2011, Whalley and Abdul-Ameer technique which applied for pipeline transportation of gases over long distances, opened the new ways to predict the original curve behaviour of system by approximating function of time parameters. This model illustrated the procedures where unite energy storage and frictional dissipation losses are considered.

Current paper is the presentation of same principle and method on crude oil pipeline. Actual project parameters and values have been applied and responses presented as follow.

5-1 Finite Element Modeling Method and Response

The first pioneer in introducing finite element model was Clough in 1960. The same method applied for solving the problems in stress analysis, fluid flow, heat transfer, and other areas. First book in finite element method is published by Zienkiewicz and Chung in 1967.
Dividing the body to the number of equivalent minor elements (finite elements) interconnected at points (nodal points or nodes), boundary lines, surfaces (discretization), Run the entire structure to a piecewise fashion.
Modeling a body by dividing it into an equivalent system of smaller bodies or units
Mathematical calculation of finite element system when only initial parameter of pipeline such as inductance, capacitance, pump and valve are considered derived in section (4-3).Whole system divided to five sections of 2 km length.
Simulation block diagram constructed in MATLAB and unit step response curve demonstrated as figure(5-1).As its clear from figure system didn't approach to the desire value and changing in volume of flow rate curve raised to 0.098 at 10^5 second .

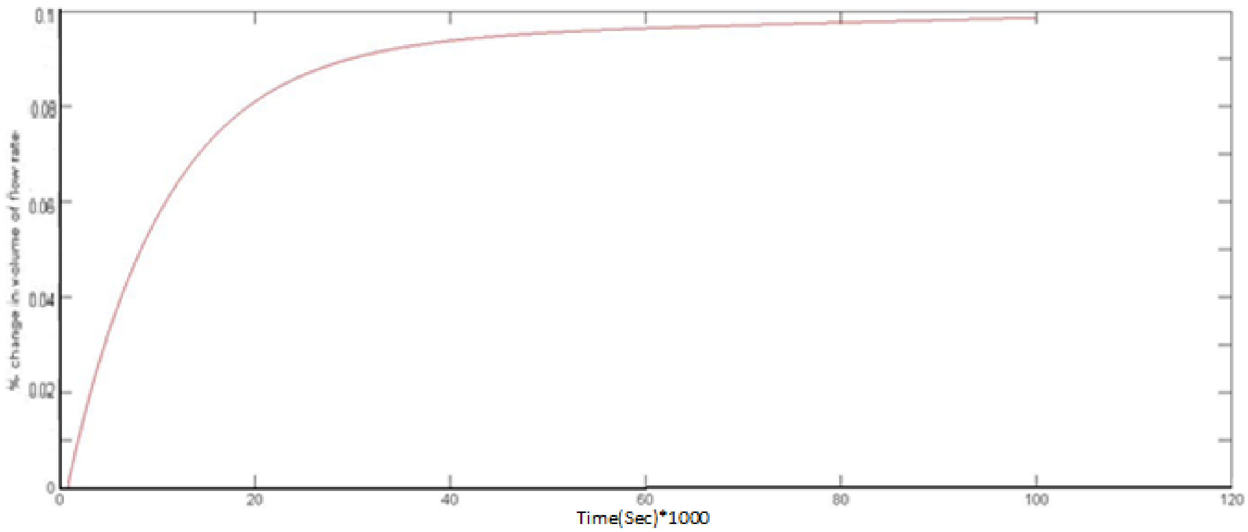


Figure (5-1) Percentage change in volume of exit flow rate of 10 km, finite element model of pipe and pump system when R & G are excluded.

Driving the same techniques for lossy system, when R and G are considered presented the numerical unstable result, which makes the system graphically impossible to run.

As a history of finite element exhibits. Applying very large matrix of arrays and mesh diagrams to calculate final behavior of system when partition's length and their interconnection are neglected refused to use by many authors and researchers. High consumption of memory is another reason to direct relevant users to simpler and more accurate techniques.

Peter and Ronal declared that dividing whole cable length to many segments and writing them in matrix is not sufficient as interconnection of elements should be considered. Hence the description of system should be consisting of individual fluid pipe elements and set of statements that shows how their voltage and currents are depend on each other which achieved by Krishhoff's law(Peter and Ronald ,1983).

5-2 Transmission Line Modeling and Response

The TLM method is new method of analyzing the system with simple numerical procedure which represents the actual circuit's parameters. The other advantage is that network is physically stable and variable kind of distributed model can be build up for the unique network.

The system lies on improvement in accuracy of the system with introducing more complicated elements to the system (Bandler, Johns, Risk, 1977).

5-2-1 Block Diagram Representation of Hybrid Model When G and R are excluded

Block diagrams of the system are consisting of the different icons which basically, each one is an illustration of particular parts of the system. For instance, state spaces, transfer function, sources, and outputs can be modeled simply by blocks without using command windows of MATLAB.

The block diagram is a way of representation of dynamic of the systems, which normally consists of blocks with their interconnection which exhibit internal states and input-output of the systems (Robert, 2008).

Baran and Furja tried to identify the parameters of a dynamic model as block diagrams. Parameters extracted from experimental elements fit the equal transfer functions. The response of the model illustrated the same result of experimental and simulation when parameter models adjusted (Baran and Furja, 1993).

Block diagram simulation of 10 km pipe transmission line, including the effects of pump, exhibited in series form as figure (5-2).

Substitution of three basic values of (ζ),$W(s)$ and $(W^2(s)-1)^{\frac{1}{2}}$ from calculated equations of (4-5-19),(4-6-5) and (4-6-6) when R and G are excluded and equations (4-7-20), (4-8-14) and (4-8-15) when losses are included, running the block diagrams, demonstrated the different transient response and steady state which will be studied precisely in the following sections.

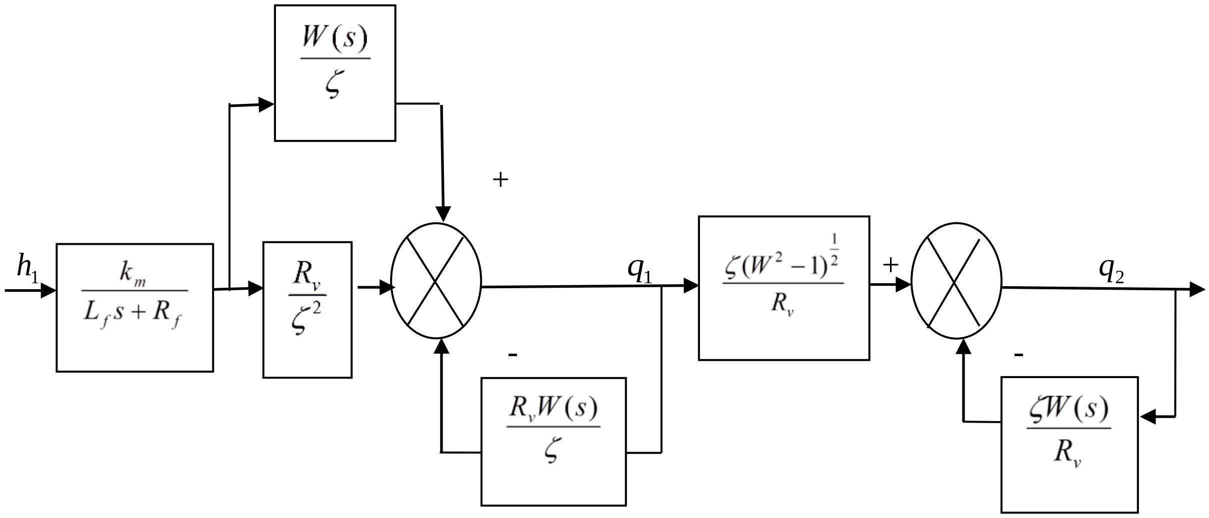


Figure (5-2) Expanded block diagram, representation of 10 km pipe-pump system in series form when losses are included and excluded.

The step over damped smooth response of the pipe and pump transmission line system when R and G are excluded, demonstrated as figure (5-3), as it is shown, the changing in volume of flow rate plot disperses slowly to reach a steady state response of 0. 1855 in 77.17×10^3 second. The rising time is approximately estimated between 1.156×10^3 and 35.11×10^3 sec.

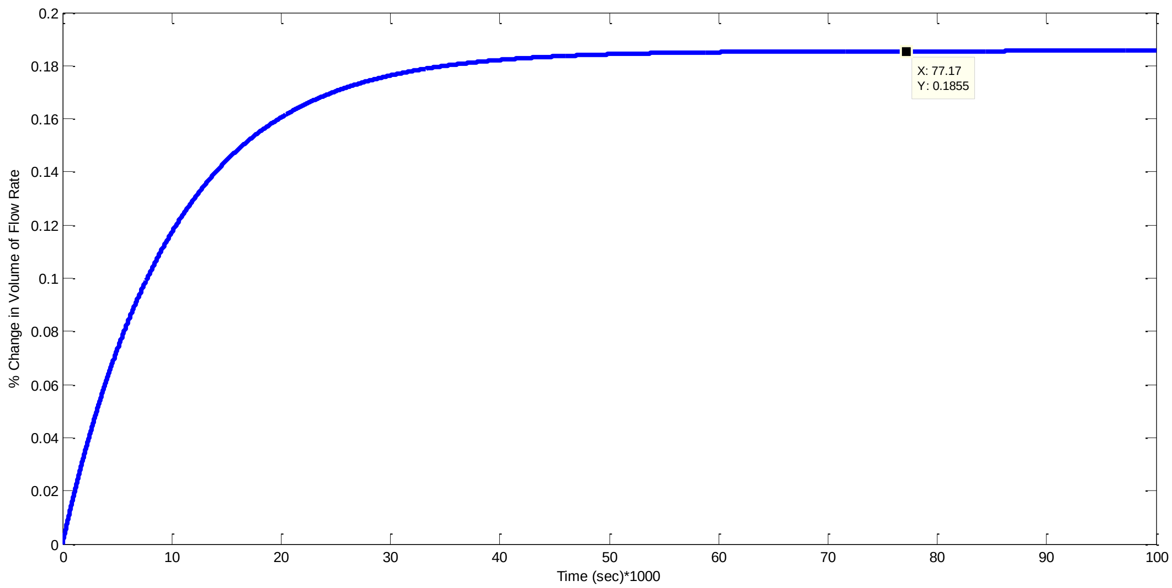


Figure (5-3) Percentage change in volume of exit flow rate of transmission line model of 100 m and 10 km **pipe and pump** system when **R & G are excluded**.

5-2-2 Block Diagram Representation of Hybrid Model When G and R are Included

Normally, block diagrams are the graphical representation of the systems transfer functions which shows the cause and effect of systems elements (William and Palm, 2010).

Block diagram simulation representation of 100 m and 10 km pipeline when the influence of pump resistance and inductance included for lossy system is as figure (5-2), where propagation, attenuation, and time delay are as calculated value of equations (4-7-20),(4-8-14) and (4-8-15), respectively.

5-2-2-1 Bode Diagram Response With one Intersection

Including R and G into the 10 km pipe line system's calculation and changes which occurred in damping ratio is illustrated as equation (4-7-20). Since ζ is the function of time, estimating the behavior of the system is impossible.

The blue graph in figure (5-4) with a slope of -20 dB is an illustration of original damping ratio transfer function. Since its function of time and under square root, second order approximated transfer function is required to eliminate the square root.

$$\zeta = \sqrt{\frac{Ls+R}{Cs+G}} = \bar{a}\sqrt{\frac{\frac{Ls}{R}+1}{\frac{Cs}{G}+1}} = \bar{a}\sqrt{\frac{(Ts+1)^2}{(\tau s+1)^2}} \quad 5\text{-}2\text{-}1$$

The estimated curve achieved by trial and error of many -40 dB slope plots to contribute two break frequencies of $\frac{1}{T}$ and $\frac{1}{\tau}$ between high and low frequency of the original transfer function. The extracted graph which intersected the original damping ratio plot in one place serves the requirement of approximation.

Figure (5-4) is an illustration of approximated transfer function with two break frequencies selected for bode characteristics are as table below:

$1/(L/R)$ **rad/sec**	$1/(C/G)$ **rad/sec**	$1/T$ **rad/sec**	$1/\tau$ **rad/sec**
$1/0.93574$	$1/0.10974$	$1/0.4667786$	$1/0.16$

Figure (5-4) demonstrated the intersection of original and estimated transfer function with magnitude of 15 dB and frequency of 7.906 second.

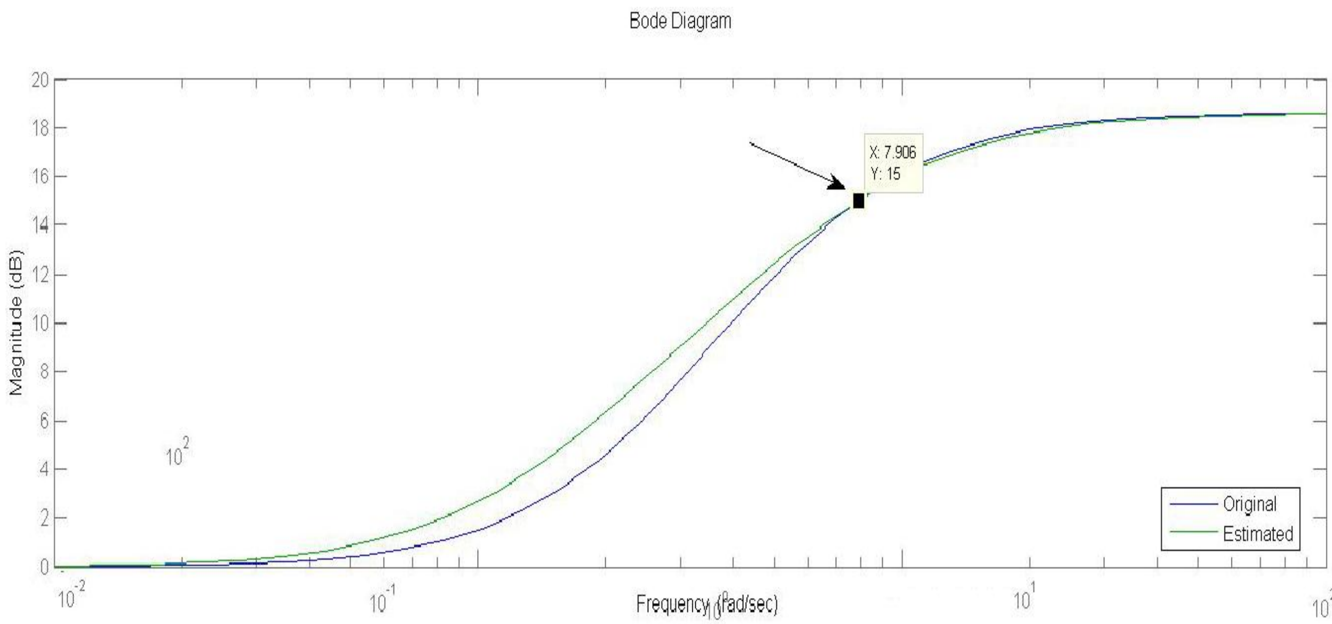
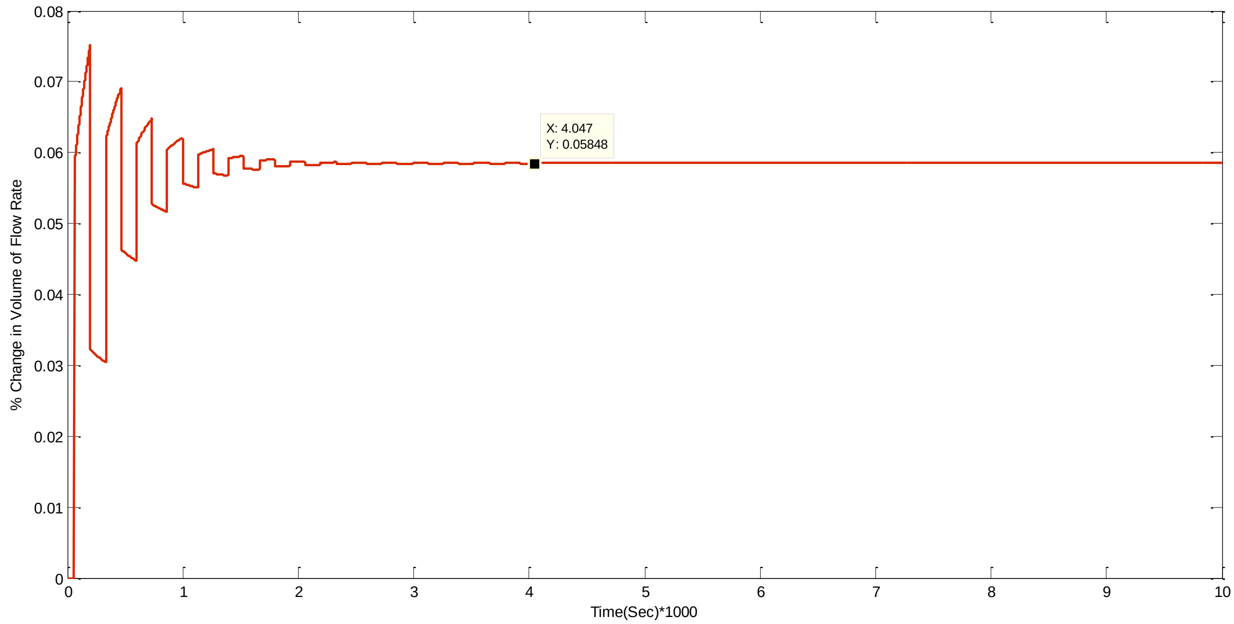


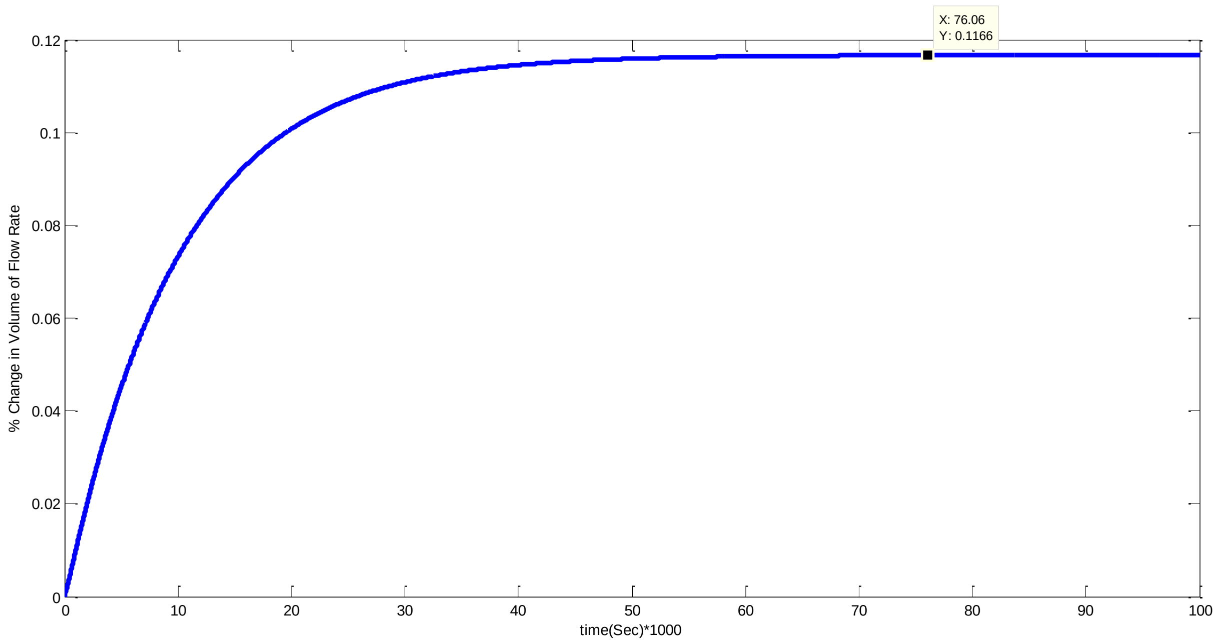
Figure (5-4) Bode diagram modulus for $\dfrac{\frac{L}{R}(s)+1}{\frac{C}{G}(s)+1}=\dfrac{0.93574s+1}{0.10974s+1}$ and $\dfrac{(Ts+1)}{(\tau s+1)}=\dfrac{(0.4667786s+1)}{(0.16s+1)}$

Unit step response of the percentage of change in flow rate when Pump is excluded from the system and losses are considered, with one T and τ is as figure (5-5). As the graph shows the system is unstable, due to excluding the effect of pump. The graph shows a high oscillation and reaches to a steady state of 0.05848 in 4.047×10^{3} second.



Figure(5-5) Percentage change in the volume of exit flow rate of 10 Km transmission line model of **pipe** when **R & G are included** and one T and one τ is estimated from the bode diagram.

Analyzing the response of the system when R and G and pump are included with unit step input is an over damped smooth plot which demonstrated as figure (5-6). As it is shown, the transient response dies out at 0.1166 in 76.06×10^3 second and the rising time is between 1.158×10^3 sec and 22.91×10^3 sec.



Figure(5-6) Percentage change in volume of exit flow rate of 10 Km transmission line model of **pipe and pump** when **R & G are included** and one T and one τ is estimated from the bode diagram.

5-2-2-2 Bode Diagram Response with Three Intersections

Approximating the transfer function with four break frequencies where intersect the original plot in three locations enhance the accuracy of the estimation. Based on the equation (4-7-20) and (4-8-7) transfer function is as below:

$$\zeta = \sqrt{\frac{Ls+R}{Cs+G}} = \bar{a}\sqrt{\frac{\frac{Ls}{R}+1}{\frac{Cs}{G}+1}} = \bar{a}\frac{(T_1 s+1)(T_2 s+1)}{(\tau_1 s+1)(\tau_2 s+1)} \qquad \text{5-2-2}$$

Four break frequencies which are selected for bode characteristics are as the following table:

$1/(L/R)$ rad/sec	$1/(C/G)$ rad/sec	$1/T_1$ rad/sec	$1/\tau_1$ rad/sec	$1/T_2$ rad/sec	$1/\tau_2$ rad/sec
$1/0.93574$	$1/0.10974$	$1/1.001$	$1/0.2618$	$1/0.6667$	$1/0.1346$

As figure (5-7) shows in addition to having the same low and high frequencies, the green estimated graph meets and intersects the original plot in three frequencies of 0.103 sec., 2.62 sec., and 35.8 sec. which satisfy the requirement of estimation.

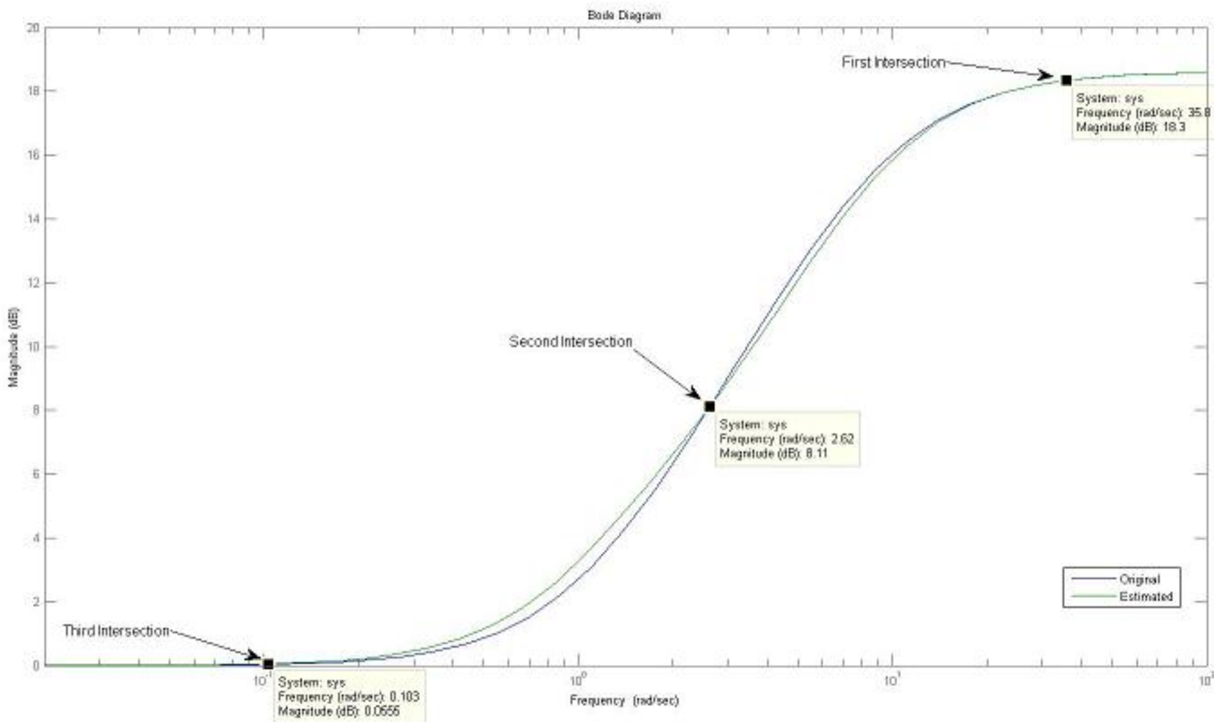
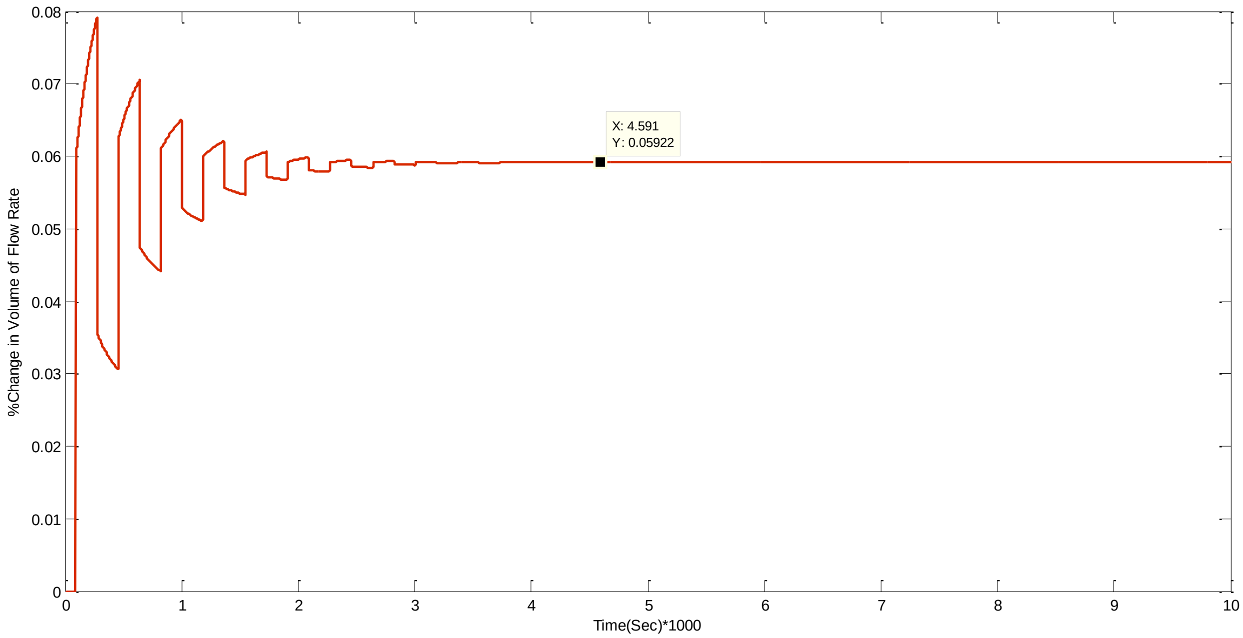


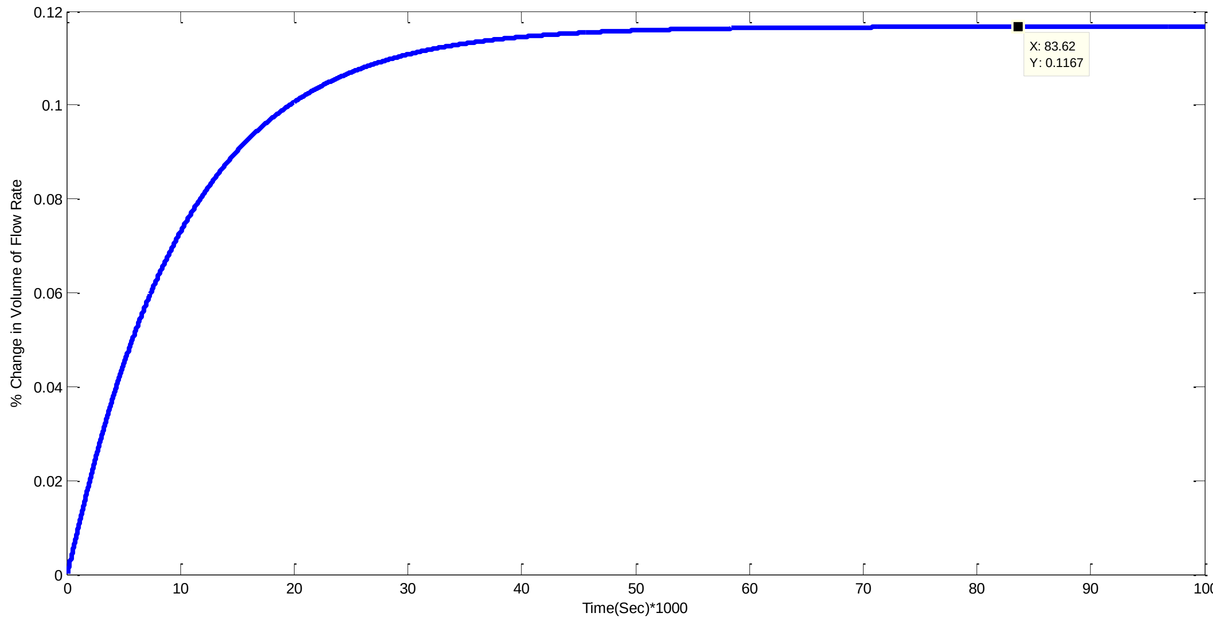
Figure (5-7) Bode diagram modulus for $\dfrac{\frac{L}{R}(s)}{\frac{C}{G}(s)} = \dfrac{0.93574s+1}{0.10974s+1}$ and $\dfrac{(T_1 s+1)(T_2 s+1)}{(\tau_1 s+1)(\tau_2 s+1)}\ \dfrac{(1.001s+1)(0.6667s+1)}{(0.2618s+1)(0.1346s+1)}$

Figure (5-8) is a response demonstration of 10 km pipeline system with losses when motor effect is excluded and two T and one τ are estimated from the bode diagram. The graph shows an unstable curve which starts to rise with 0.091 second delay and reaches to the highest value of 0.0793. It oscillates and eventually approaches to the steady state rate of 0.05922 in 4.591×10^3 second.



Figure(5-8) Percentage change in the volume of exit flow rate of 10 Km transmission line model of **pipe** when **R & G are included** and two T and one τ are estimated from the bode diagram.

The evaluation of system response when R and G and pump are included with unit step input and two estimated T and τ is an over damped smooth plot which demonstrated as figure(5-9). As it is shown, unit step response curve reached to the steady state response at 0.1167 in 83.62×10^3 second and the rising time is between 1.221×10^3 sec. and 23.5×10^3 sec .



Figure(5-9) Percentage change in the volume of exit flow rate of 10 Km transmission line model of **pipe and pump** when **R & G are included** and T_1, T_2 and τ_1, τ_2 are estimated from the bode diagram

5-3 Result Summary and Model Comparison

10 km pipe line has modeled with two different techniques of Finite element and lumped – distributed parameter. The transmission line model constructed is based on transfer functions which are calculated initially according to the model of Abdul Ameer and Whalley (2011).

Project actual values applied to each one and model comparison conducted based on extracted graphs of which details can be found as follow:

Preliminary finite element model constructed based on L and C as basic elements of the pipeline which substituted with actual values of B, g, and A, calculated values achieved as 9.357422×10^{-4} and 2.79086×10^{-7} respectively.

The lossless finite element model of pipeline was divided into five sections and relevant equations and matrixes have run in a maple. The simulation model of finite element was built up and the system ran for 100 seconds. The unit step response illustrated an over damped curve which never reached the desire value of inlet flow rate. However, a very slow unstable outlet response demonstrated the poor behavior of finite element technique which can be due to neglecting the section length and propagation waves.

Accordingly, including R and G and running the finite element mathematical model based on a combination of four parameters, illustrated the numerical unstable response as inverse goes very long and impossible to simulate.

The constructed block diagram representation of hybrid pipeline displayed as figure (5-2). The same model for lossy and lossless system was built in MATLAB.

Including the losses into the calculation of distributed-lumped model, L/R and C/G become function of time and demonstrate an unknown behavior of the system. In order to overcome the issue, the approximated T and τ , break frequencies extracted when the estimated graph intersectes the original graph in one and three locations. The more intersection shows th higher accuracy of estimation of original transfer function.

Comparison of figures (5-6) and (5-9) for one and three intersections of 10 km pipeline when losses and pump influences are considered reflect the truth of the higher accuracy of more break frequencies. The graph figure (5-9) reaches to a higher steady state of 0.1167 in longer time than (5-8) with a steady state value of 0.1166. The Longer time steady state might affect the overall performance of the system; this shows the delay in the following equipment action, and accordingly the delay of the whole system. However, since a higher percentage of volume rate exits from the outlet , the distributed-lumped technique with a higher estimated intersection was defined and most acceptable model of calculation.

Chapter VI

Conclusions and Recommendations

The study was set out to predict the behavior of system and measure the overall outlet flow of rigid, uniform crude oil pipe transmission line.

Pressure losses could occurr due to fittings (elbows, flanges, reducers), pipe internal corrosion, welds or any other kinds of discontinuities. Pipe material, length, and diameter play significant roles in reducing the level of pressure and flow rate. Nowadays, software markets, such as OLGA and HYSIS are assisting the manufactures and consultancy companies to simulate the pressure and flow rate behavior along the whole pipeline.
In spite of that, predicting the behavior of flow is still under study in many research associations. The aforesaid discontinuity in the length of pipe could cause considerable resistances and disturbances, which are classified as series resistance and shunt resistance, and as history of transmission line declared, it was neglected in many papers due to increasing the complexity of computation.
The current paper presents the simulation model of 10 km lumped-distributed pipeline. The result illustrated less errors in the response of lossless model compared with the same kind when series and shunt resistance were employed.

Moreover, the higher level of accuracy demonstrated when a nearer approximation was estimated for the characteristic impedance.

The finite element mathematical calculation ran for both systems with two and four parameters, and the simulation response was compared in order to give an overall conclusion, advantages and disadvantages of techniques.

The final simulation result of lossy and lossless finite elements were compared, discussed, and proved that increasing the number of segments enhanced the complexity of calculation as a higher number of L, C, R and G are defined and applied. Dividing the whole system to ten sections exceeded the available storage memory of computer. Partitioning the whole length to nine, eight, seven, and six sections received the same comment. However, LC five sections model found the first system that could be run in Maple and does not conflict with the memory consumption. It illustrated the reasonable computation which enabled the author to simulate the block diagrams and examine the plot's results. In spite of that, adding two other parameters of system losses exhibited the long computation which was numerically unstable.

LC finite element extracted plot illustrated the unstable response of the system which output change in the volume of flow rate hardly rose to ten percent of desired value.

The numerical techniques which was introduced earlier by Johns and Beurle for solving two-dimensional scattering problems and later by Johns and Akhtarzad for three dimensions when the effect of losses included, they did not find as strong as current techniques. However, Alaa Ameer and Whalley method neglected two other space coordinates to avoid more complexity in computation. Expanding the subjected model and simulating the whole system in two and three dimensions could introduce and illustrate a more accurate overview of the system behavior. Future work can also solve the problem for the heavier fluids, in order to anticipate the reaction of system with higher resistance. It is definitely expected to affect significantly on the outlet pressure and volume of flow rate.

Assigning the flow as uncompressible and laminar is too ideal situations for fluid behavior. Walls shear stress is foreseen to be affected dramatically, when turbulent and comprisable flow pass through. Running the system with forces and disturbances when actual conditions of fluid are applied In further work, they might help the relevant companies to utilize the whole system more precisely, and assist them to build up safer and more riskless pipeline.

Chapter VII

References

Stecki, J., and Davis, D. "*Fluid Transmission Lines-Distributed Parameter Models",* Part 1: A Review of the State of the Art", Proc. Instn. Mech. Engrs. Part A, 200, 215-228. (1986).

Watton, J., Tadmori, J. M.," *A comparison of techniques for the analysis of transmission line dynamics in electrohydraulic control system*", Appl. Math. Modeling,Vol.12, (October 1988).

Bartos, R. D." *Dynamic modeling of fluid transmission lines of the DSN 70-meter antennas by using a lumped parameter model*". The Telecommunications and Data Acquisition Report, 162-169, (1992).

Yang, W. C., Tobler, W. E." *Dissipative Model Approximation of Fluid Transmission Lines Using Linear Friction Model",* Journal of dynamic system, measurement and control,Vol. 113, (March 1991).

Trikha, A. K*. ,"An efficient method for simulating frequency dependent friction in transient liquid flow*", Journal of fluids Engineering, (March 1975).

Zielke, W.,"*Frequency dependent friction in transient pipe flow",* Journal of Basic Engineering, (March 1968).

Whalley, R., Abdul-Ameer, A., and Ebrahimi, K. M. "*mechanism and machine theory*", Journal of Mechanism and Machine theory, Vol. 45, Issue 8. (August 2011).

Woods, R..L. and Lawrence, K.L,. "*Modeling and Simulation of Dynamic Systems"*,Prentice-Hall,(1997).

Dorf, R.C and Bishop,R.H," *Modern Control Systems",* Prentice-Hall, (2001).

Kirshner, M and Silas Katz, "*Design Theory of Fluidic Components"*,Academic Press, Inc., (1975).

Fung, Y.C, *A First Course In Continuum Mechanics*, Prentice-Hall, (1994).

Iberall, A.S, *Attenuation of oscillatory pressures in instrument lines.* J. Res. Nat. Bur. Stand. 45, Res. Paper 2115 ,(1950).

Gerlach, C. R. "*Dynamic Models for Viscous Fluid Transmission Lines*", Proceedings of the 10th Joint Automatic Control Conference, Boulder, Colorado, 1969.

Goodson, R. E., and Leonard, R. G. "*A Survey of Modeling Technique for Fluid Transmission Line Transients*", Journal of Basic Engineering, ASME Transactions, Series D, Vol. 94, June 1972.

Woods, R.L., *"The Effects of Source and Load Impedance Connected to Fluid Transmission Lines",*Fluid Transmission Lines Dynamics, ASME Special Publication, New York, November (1981).

Alyadi, J. Y., "*Mathematical Modeling for pump controlled system of Hydraulic drive unit* ", Vol. 2, No. 3, pp. 157-162 (1995).

Douglas, A.K ,Katrina .M. S and Juan L. B., "*Feasibility Study of a High-Voltage DC & AC Multi-Circuit Hybrid Transmission Line*",IEEE , (2005).

Drew, A.," *1901 transmission line the great Carquinez Straits crossing "*IEEE Power & Energy magazine,Vol.10 ,may & June 2010,pp 80-88

Mariki, G.E, Yeh.C. ,*"Dynamic Three-Dimensional TLM analysis of Microstriplines on* *anisotropic Substrate*",IEEE Transaction on microwave theory and techniques,Vol .MTT-33,No.9,Septemebr (1985).

Clayton, R. Paul., "*A Brief History of Work in Transmission Lines for EMC Applications*", IEEE Transaction on electromagnetic compatibility, Vol. 49, NO. 2, May(2007),pp 237-252.

Garcia, N and Acha, E.," *Transmission Line Model with Frequency Dependency and Propagation Effects: a Model Order Reduction and State-Space Approach*",2008, pp 1-7

Feng, G, Wang,Y and Zhang,B., *"Study on Electromagnetic Environment of Multi-circuit Transmission Lines on Same Tower*",IEEE,(2008).

Joseph,M., "*Dual-Level Transmission Line Model for Current Flow in Metal-Semiconductor Contacts*" IEEE transaction on electronic devices, Vol. Ed 33,NO. 11, November (1986).

NG, F.L.,"*Tabulation of methods for the numerical solution of the hollow waveguide problem*", IEEE Trans.,(1974), MTT-22, pp. 322-32.

Akhtarzad,S., and Johns,P.B ,"*Generalized elements for T.L.M method of numerical analysis* "PROC. IEE, Vol. 122, No. 12, December (1977).

Breitholtz. C, Molander .M & Navarro. R ," *Space and time continuous lumped transmission line model"* ,IEE PROCEEDINGS-G, Vol.138,No.6,December 1991,pp661-670.

Johns P.B & Beurle R.L,"*Numerical solution of 2-dimensional scattering problems using a transmission-line matrix",* Proc. IEE, Vol. 118, No. 9, September 1971.

Wolfgran ,J. R. ,"*The Transmission-Line Matrix Method Theory and Applications*", 882 IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. MTT-33, NO.

10, October 1985.

Rudge .W, Adatia .N.A., "*Analysis of wide range of microwave resonators ,TLM method* ", ELECTRONICS LETTERS 27th November(1975) Vol. 11 No. 24.

Akhtarzad,S. Johns, P.B , *Solution of 6-component electromagnetic fields in three space dimensions and time by T.L.M. Method* ", Electronic Letters 1,Vol. 10,No. 25/26,December (1974).

Johns,P.B, "*On the Relationship Between TLM and Finite-Difference Methods for Maxwell's Equations*", IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES,VOL. MTT-35, NO. 1, JANUARY(1987).

Akhtarzad.S, Johns .P.B, "T.L.M. Analysis of the dispersion characteristics *of micro strips lines on magnetic substrates using three dimensional resonators"*, IEEE, Vol.11, Nov.6, March 1975.

.

DARWISH, .A , EZZEDDINE.A,"*THREE DIMENSIONAL TRANSMISSION LINES AND SPECIAL ELEMENTS DESIGN*", IEEE MTT-S Digest, MO2C-4, pp. 131-134, 1999.

Tenorio, C.A, ,de Menezes R.A.X. "*Extraction of S-Parameter Using the Three-Dimensional Transmission-Line Matrix(TLM) Method*",IEEE. 2003

Thomson. W,. "*The theory of the electric telegraph,"* in Proc. Royal Society, vol. VII, May 1855, p. 382.

Kirchhoff. G ,"*On the motion of electricity in wires,"*inPhil.Mag.,vol. XIII, 1857, pp. 393–412.

Heaviside. O," *Electromagnetic Theory*", O. E. and F. N. SPON LTD, Ed. London, U.K., 1951.

Abul-Ameer, A.A, "*Mathematical Modeling and Simulation of Mechanical Systems*", PhD. Thesis, University of Bradford, UK, (2001).

Lorenz, P and Russer .P,"*Hybrid Transmission Line Matrix (TLM) and Multipole Expansion Method for Time-Domain Modeling of Radiating Structures*", IEEE MTT, 2004.

Ikeda,S. Sato.T, Ohshiro.A, Yamasawa.K, "*A Thin Film Type Magnetic/Dielectric Hybrid Transmission-Line with a Large Wavelength Shortening*", IEEE TRANSACTIONS ON MAGNETICS, VOL. 37, NO. 4, JULY(2001).

Iijima, Y., Murakawa, M. Kasai, Y. Takahashi, E ,."*Proposal of Transmission Line Modeling using Multi-Objective Optimization Techniques*", IEEE Congress on Evolutionary Computation, (2007)

Moore, E. F.," *The small signal response of fluid transmission lines, including developed mean flow effects* "[ph.D. thesis final technical report, 3 jan. 1973 – 16 dec.(1978).
"The Small Signal Response of Fluid Transmission Lines, Including Developed Mean Flow Effects ",Ph.D.Thesis Final Technical Report, 3 Jan.1973 - 16 Dec.1977.

Ito.K, Ravindran.S. S.*," A Reduced Order Method for Control of Fluid Flows*" Proceeding on the 35th Conference on Decision and Control Kobe, Japan,December (1996).

Roger, C. H, Jane .Z.H., "*Robust Analysis of Optimal Flow Control for Reducing Fluid Transients*"IEEE, (1991).

Shanker.B, Kempel .L.C, Tuncer.O, Lu.C,Nair .N,. "*Analysis of Error Propagation in Vector Generalized Finite Element Methods",*IEEE,(2007).

Lu, C and Shanker, B.,"*Hybrid Boundary Integral-Generalized (Partition of Unity) Finite-Element Solvers for the Scalar Helmholtz Equation*", IEEE TRANSACTIONS ON MAGNETICS, VOL. 43, NO. 3, March (2007).

Saxena, P., "*Modeling and simulation*", Alpha science International Ltd, (2001).

Peter P.S and Ronald L.F," *finite element for electrical engineers*", Cambridge university,(1983).

Bandler, .J.W, Johns P.B ,Risk .R.M,. "*Transmission- Line Modeling and Sensitivity Evaluation for -Lumped Network Simulation and Design in the Time Domain***",** Conference on Computer-aided Design of Electronic and Microwave Circuits and Systems. Hull,July (1977).

Robert G.L,." *Modeling and Analysis of Dynamic" Systems*" Missouri S&T,(2008).

Dhaene, T ,De Zutter.D .,"*Selection of lumped element model for coupled lossy transmission line*" IEEE transaction on computer and aided design, Vol. 11,No.7,July (1992).

Brown, F.T.," *Transient Response of Fluid Lines*", J. Basic Engineering ,Volume 84, Issue 4, 547 -514, December (1962) .

Baran, E , Forja. A.H.*," IDENTIFICATION OF PARAMETERS OF A BLOCK DIAGRAM DYNAMIC MODEL"*, North Carolina State University Raleigh,IEEE,(1993).

Gardner, J.F, Shearer,J.L .,"*Dynamic modeling and control of engineering system"*, Cambridge university,(2007).

William.J, Palm III,"*System Dynamic*",Mc Graw Hill,(2010).

Lee.S.Y , Konrad.A*,"Lossy transmission line transient Analysis by the finite element method",* Transaction on Magnetics IEEE, VOL. 29, NO. 2, March (1993).

Abul-Ameer, A.A, “*The Modeling and Simulation of Gas Pipeline Dynamics*”, Proceeding of the 8th WSEAS International Conference on Dynamical Systems and Control (CONTROL 12), Porto, Portugal, pp 82-89, July 1-3,(2012).

Whalley, R, Abdul-Ameer, A.A , Ebrahimi, M ,”*Machine tool modelling and profile following performance*” , Journal applied Mathematical Modeling, Volume 32, Issue 11,Pages 2290–2311, November (2008) .

John, D .K, “Frequency *response approximation methods of the dissipative model of fluid transmission lines”*, Faculty of the Graduate School of The University of Texas at Arlington, May (2006).

Sleigh, A,” *An Introduction to Fluid Mechanics*”, School of Civil Engineering, University of Leeds.CIVE1400 FLUID MECHANICS, May (2001).

Maffucc , A , Miano ,G , Villone , F, ” *An Enhanced Transmission Line Model for Conducting Wires” ,* IEEE transaction on electromagnetic compatibility, VOL. 46, NO. 4, November (2004).

Whalley, R. and Abdul-Ameer, A., “Heating, Ventilation and Air Conditioning System Modelling”, Elsevier, Journal of Building and Environment, Vol. 46, pp. 643-656, (2011).

Alan, D , “*1901 Transmission Line the great Carquinez Straits crossing History*", IEEE Power and Energy Magazine, (2010).

Whalley, R. and Abdul-Ameer, A., “*The Dynamics of Cyclic Ventilation Systems*”, Elsevier, Journal of Applied Mathematical Modelling, Vol. 35, pp. 93-108,(2011).

Bradley , D. Duncan , Poon ,T.C ," *Gaussian beam analysis of optical scanning holography*", Journal of the optical society of America ,JOSA A, Vol. 9, Issue 2, pp. 229-236 (1992).

Clayton, R.P, *"A Brief History of Work in Transmission Lines for EMC Applications*", IEEE transaction on electromagnetic compatibility, VOL. 49, NO. 2, May (2007).

Martin, P, Milan, J. D. R, "*Robot arm reaching through neural inversions and reinforcement learning*", Robotics and Autonomous Systems, 227–246, 31 (2000).

Willner, A .E, Pan, Z, "*Optical communication", The handbook of photonic*", second edition ,pp. 20-149,(2006).

Oksendal, B, "*Optimal Control of Stochastic Partial Differential Equations*", Stochastic Analysis and Applications, Volume 23, Issue 1, pp. 165-179, (2005).

Ida, M.T, "*The History of the Standard Oil Company*", Vol 2,(1904), http://www.pipeline101.org/History/timeline.html

Web sources

http://www.pumpschool.com/applications/Fuel_Oil.pdf

http://www.pipeline101.org/History/timeline.html

http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Continuity_Equation.htm

http://processcamp.ir/files/attach/1341498669.pdf

http://www.postech.ac.kr/class/me14743/lecturenote/FluidStatics.ppt

http://www.bppipelines.com/history.html

http://ahmadkamal.my-place.us/analysis.html

http://www.efm.leeds.ac.uk/CIVE/CIVE1400/PDF/Notes/section3.pdf

http://www.lycee-saint-cricq.org/site/IMG/pdf/handbook_vanne_chap4_5.pdf

http://www.netl.doe.gov/technologies/coalpower/cctc/cctdp/bibliography/demonstration/pdfs/healy/90544R95.pdf

VIII: Appendix 1

8-1 Actual of Sabzab to Tang-i-Fanni Pipeline Project Values

Symbol	Description	Unit	Value
D	Pipeline diameter	Inch	30
l	Pipeline length	Meter	100-10000
g	Crude oil specific weight	Gr	0.8876
ν	Crude oil Kinematic viscosity	Cst	29.13
θ	Absolute crude oil Temperature	Celsius	10
ρ	Crude oil density	kg/m^3	886.6
V_e	Crude oil erosional velocity	m/s	2.2432
R_v	Control Valve Resistance	Ohm	10.612
B	Pressure wave propagation speed	m/s	1449616
L	Pipe inductance per unit length	Henry/Meter	9.357422×10^{-4}
C	Pipe capacitance per unit length	Farad/Meter	2.79086×10^{-7}
R	Pipe resistance per unit length	Ohm/Meter	10^{-4}
G	Pipe shunt resistance per unit length	Ohm/Mater	2.543×10^{-6}
k_m	Motor constant	Nm/A	15.563
L_f	Motor resistance	Ohm	70.9
R_f	Motor inductance	H	7.9

8-2 Fundamental Elements Calculation

$$Q = V_e \times A = 2.2432 \times 1.82322 = 4.09 \quad 8\text{-}1\text{-}1$$

$$L = \frac{1}{gB} = \frac{1}{0.8876 \times 1204} = 9.357422 \times 10^{-4} \quad 8\text{-}1\text{-}2$$

$$C = \frac{gA}{B^2} = \frac{0.8876 \times 0.4558}{1449616} = 2.79086 \times 10^{-7} \quad 8\text{- }1\text{-}3$$

$$G = \frac{g}{B^2} Q = \frac{0.8876}{1449616} \times 4.09 = 2.543 \times 10^{-6} \quad 8\text{-}1\text{-}4$$

$$\Delta h = R_v \frac{V_e^2}{2g} \quad 8\text{-}1\text{-}5$$

$$R_v = \frac{\Delta h \times 2g}{V_e^2} = \frac{100 \times 2 \times 0.8876}{(4.09)^2} = 10.612 \quad 8\text{-}1\text{-}6$$

8-3 Mathematical Calculation of Lossless System for 100m Pipeline

$$\zeta = \sqrt{\frac{L}{C}} = \sqrt{\frac{9.357422 \times 10^{-4}}{2.79086 \times 10^{-7}}} = \sqrt{3.35288 \times 10^{5}} = 57.90406 \quad 8\text{-}2\text{-}1$$

$$T = 2l\sqrt{LC} = 2 \times 100 \times \sqrt{2.79086 \times 10^{-7} \times 9.357422 \times 10^{-4}} = 3.23154 \times 10^{-3} \quad 8\text{-}2\text{-}2$$

$$W(s) = \frac{1 + e^{-2l\Gamma}}{1 - e^{-2l\Gamma}} = \frac{1 + e^{-sT}}{1 - e^{-sT}} = \frac{1 + e^{-3.23154\times10^{-3}s}}{1 + e^{-3.23154\times10^{-3}s}} \quad 8\text{- }2\text{-}3$$

$$(W^2(s) - 1)^{\frac{1}{2}} = \frac{2e^{-sT/2}}{1 - e^{-sT}} == \frac{1 + e^{-1.6645\times10^{-3}s}}{1 + e^{-3.23154\times10^{-3}s}} \quad 8\text{-}2\text{-}4$$

8-4 Mathematical Calculation of Lossless System of 10 km Pipeline

$$T = 2l\sqrt{LC} = 2\times10^4 \times \sqrt{2.79086\times10^{-7}\times 9.357422\times10^{-4}} = 0.323154 \qquad \text{8- 3-1}$$

$$W(s) = \frac{1+e^{-2l\Gamma}}{1-e^{-2l\Gamma}} = \frac{1+e^{-sT}}{1-e^{-sT}} = \frac{1+e^{-3.23154s}}{1+e^{-3.23154s}} \qquad \text{8- 3-2}$$

$$(W^2(s)-1)^{\frac{1}{2}} = \frac{2e^{-sT/2}}{1-e^{-sT}} == \frac{1+e^{-1.6645s}}{1+e^{-3.23154s}} \qquad \text{8- 3-3}$$

8-5 Mathematical Calculation of Lossy System of 100 m with One T and τ

$$(\frac{L}{R}s+1)/(\frac{C}{G}s+1) = (9.357422+1)/(0.109746+1) \qquad \text{8- 4-1}$$

With

$$T = 0.4667786 \text{ and } \tau = 0.16 \qquad \text{8-4-2}$$

$$\zeta = \sqrt{\frac{R}{G}}\sqrt{\frac{(Ts+1)^2}{(\tau s+1)^2}} = \sqrt{\frac{10^{-4}}{2.543\times10^{-6}}}\sqrt{\frac{(0.4677s+1)^2}{(0.16s+1)^2}} = 6.27085\frac{0.4677s+1}{0.16s+1} \qquad \text{8-4-3}$$

$$a = [\frac{C}{G}+T+\tau] = \frac{2.79086\times10^{-7}}{2.543\times10^{-6}} + 0.467786 - 0.16 = 0.417446 \qquad \text{8-4-4}$$

$$b = 1 \qquad \text{8-4-5}$$

$$\alpha = \sqrt{RG} = \sqrt{10^{-4}\times 2.54\times10^{-6}} = 1.594678\times10^{-5} \qquad \text{8-4-6}$$

Attenuation : $e^{-2l\alpha b} = e^{-2(100)(1.594678\times10^{-5})(1)} = 0.996815$ 8-4-7

$$e^{-2l\alpha as} = e^{-2(100)(1.594678\times10^{-5})(0.417446)s} = e^{-1.33136\times10^{-3}s} \qquad \text{8- 4-8}$$

$$W(s) = \frac{1+e^{-2l\alpha(as+b)}}{1-e^{-2l\alpha(as+b)}} = \frac{1+0.996815e^{-1.33136\times10^{-3}s}}{1-0.996815e^{-1.33136\times10^{-3}s}} \qquad \text{8-4-9}$$

$$(W^2(s)-1)^{\frac{1}{2}}=\frac{2e^{-l\alpha(as+b)}}{1-e^{-2l\alpha(as+b)}}=\frac{1.9968e^{-0.6656\times10^{-3}}}{1-0.996815e^{-1.33136\times10^{-3}s}} \quad 8\text{-}4\text{-}10$$

8-6 Mathematical Calculation of Lossy System of 10 km with One T and τ

Attenuation $e^{-2l\alpha b}=e^{-2(10^4)(1.594678\times10^{-5})(1)}=0.72692$ 8- 5-1

Time delay : $e^{-2l\alpha as}=e^{-2(10^4)(1.594678\times10^{-5})(0.417446)s}=e^{-1.33138s}$ 8-5-2

$$W(s)=\frac{1+e^{-2l\alpha(as+b)}}{1-e^{-2l\alpha(as+b)}}=\frac{1+0.72692e^{-1.33138s}}{1-0.72692e^{-1.33138s}} \quad 8\text{-}5\text{-}3$$

$$(W^2(s)-1)^{\frac{1}{2}}=\frac{2e^{-l\alpha(as+b)}}{1-e^{-2l\alpha(as+b)}}=\frac{3.41038e^{-0.66569s}}{1-0.726925e^{-1.33138\times10^{-3}s}} \quad \textbf{4-14} \quad 8\text{-}5\text{-}4$$

8-7 Mathematical Calculation of Lossy System of 10 km with Two T and τ

$T_1=1.001, \mathrm{T}_2=0.2618, \tau_1=0.6667, \tau_2=0.1346$ 8- 6-1

$$\bar{\alpha}=\sqrt{\frac{R}{G}}=\sqrt{\frac{10^{-4}}{2.543\times10^{-6}}}=\sqrt{\frac{100}{2.543}}=6.27085 \quad 8\text{-}6\text{-}2$$

$$\zeta=\bar{\alpha}(\frac{T_1 s+1}{\tau_1 s+1})(\frac{T_2 s+1}{\tau_2 s+1})=6.27085\frac{(1.0010s+1)(0.2618s+1)}{(0.6667s+1)(0.346s+1)}=$$
$$6.27085\frac{0.2621s^2+1.2628s+1}{0.0897s^2+0.8013s+1} \quad 8\text{-}6\text{-}3$$

$$a=[\frac{C}{G}+(T_1+T_2)-(\tau_1+\tau_2)]=$$
$$\frac{2.79086\times10^{-7}}{2.543\times10^{-6}}+(1.0010+0.2618)-(0.6667+0.1346)=0.5712466 \quad 8\text{-}6\text{-}4$$

$b=1$ 8-6-5

$$\alpha = \sqrt{RG} = 1.594678 \times 10^{-5} \qquad 8\text{-}6\text{-}6$$

Attenuation: $e^{-2l\alpha b} = e^{-2(10^4)(1.594678\times 10^{-5})(1)} = 0.72692$ 8-6-7

Time delay: $e^{-2l\alpha as} = e^{-2(10^4)(1.594678\times 10^{-5})(0.571246)s} = e^{-0.1821897s}$ 8-6-8

$$W(s) = \frac{1+e^{-2l\alpha(as+b)}}{1-e^{-2l\alpha(as+b)}} = \frac{1+0.72692e^{-0.1821897s}}{1-0.72692e^{-0.1821897s}} \qquad 8\text{-}6\text{-}9$$

$$(W^2(s)-1)^{\frac{1}{2}} = \frac{2e^{-l\alpha(as+b)}}{1-e^{-2l\alpha(as+b)}} = \frac{1.70519e^{-0.0910948s}}{1-0.72692e^{-0.1821897s}} \qquad 8\text{-}6\text{-}10$$

IX: Appendix 2

9-1 Finite Element Calculation of Pipeline

9-1-1 Finite Element Calculation of Pipeline Divided to 10 Sections:

Simulating the Finite element of the pipeline when system is divided to 10 sections is impossible as length of output inverse exceed the limit of 10000 digits.

$$
\begin{array}{l}
a11 := L1.s + \frac{1}{C1 \cdot s};\ a12 := -\frac{1}{C1.s};\ a13 := 0; \\
a14 := 0;\ a15 := 0;\ a16 := 0;\ a17 := 0;\ a18 \\
:= 0;\ a19 := 0;\ a110 := 0;\ a21 := -\frac{1}{C1.s}; \\
a22 := L2.s + \frac{1}{C2.s} + \frac{1}{C1 \cdot s};\ a23 := \\
-\frac{1}{C2.s};\ a24 := 0;\ a25 := 0;\ a26 := 0;\ a27 \\
:= 0;\ a28 := 0;\ a29 := 0;\ a210 := 0;\ a31 \\
:= 0;\ a32 := -\frac{1}{C2.s};\ a33 := L3.s + \frac{1}{C3.s} \\
+ \frac{1}{C2.s};\ a34 := -\frac{1}{C3.s};\ a35 := 0;\ a36 := 0; \\
a37 := 0;\ a38 := 0;\ a39 := 0;\ a310 := 0;\ a41 \\
:= 0;\ a42 := 0\ ;\ a43 := -\frac{1}{C3.s};\ a44 := L4.s \\
+ \frac{1}{C4.s} + \frac{1}{C3.s};\ a45 := -\frac{1}{C4.s};\ a46 := 0; \\
a47 := 0;\ a48 := 0;\ a49 := 0;\ a410 := 0;\ a51 \\
:= 0;\ a52 := 0\ ;\ a53 := 0;\ a54 := -\frac{1}{C4.s};\ a55 \\
:= L5.s + \frac{1}{C5.s} + \frac{1}{C4.s};\ a56 := -\frac{1}{C5.s};\ a57 \\
:= 0;\ a58 := 0;\ a59 := 0;\ a510 := 0;\ a61 \\
:= 0;\ a62 := 0\ ;\ a63 := 0;\ a64 := 0;\ a65 := \\
-\frac{1}{C5.s};\ a66 := L6.s + \frac{1}{C6.s} + \frac{1}{C5.s};\ a67 := \\
-\frac{1}{C6.s};\ a68 := 0;\ a69 := 0;\ a610 := 0;\ a71 \\
:= 0;\ a72 := 0\ ;\ a73 := 0;\ a74 := 0;\ a75 \\
:= 0;\ a76 := -\frac{1}{C6.s};\ a77 := L7.s + \frac{1}{C7.s}
\end{array}
$$

$$
\begin{array}{l}
+ \frac{1}{C6.s};\ a78 := -\frac{1}{C7.s};\ a79 := 0;\ a710 \\
:= 0;\ a81 := 0;\ a82 := 0\ ;\ a83 := 0;\ a84 \\
:= 0;\ a85 := 0;\ a86 := 0;\ a87 := -\frac{1}{C7.s};\ a88 \\
:= L8.s + \frac{1}{C8.s} + \frac{1}{C7.s};\ a89 := -\frac{1}{C8.s}; \\
a810 := 0;\ a91 := 0;\ a92 := 0\ ;\ a93 := 0;\ a94 \\
:= 0;\ a95 := 0;\ a96 := 0;\ a97 := 0;\ a98 := \\
-\frac{1}{C8.s};\ a99 := L9.s + \frac{1}{C9.s} + \frac{1}{C8.s};\ a910 \\
:= -\frac{1}{C9.s};\ a101 := 0;\ a102 := 0\ ;\ a103 := 0; \\
a104 := 0;\ a105 := 0;\ a106 := 0;\ a107 := 0; \\
a108 := 0\ ;\ a109 := -\frac{1}{C9.s};\ a1010 := Rv \\
+ \frac{1}{C9.s};
\end{array}
$$

$$a11 := L1.s + \frac{1}{C1\ s}$$

$$a12 := -\frac{1}{C1.s}$$

$$a13 := 0$$

$$a14 := 0$$

$$a15 := 0$$

$$a16 := 0$$

$a17 := 0$

$a18 := 0$

$a19 := 0$

$a110 := 0$

$a21 := -\frac{1}{C1.s}$

$a22 := L2.s + \frac{1}{C2.s} + \frac{1}{C1\ s}$

$a23 := -\frac{1}{C2.s}$

$a24 := 0$

$a25 := 0$

$a26 := 0$

$a27 := 0$

$a28 := 0$

$a29 := 0$

$a210 := 0$

$a31 := 0$

$a32 := -\frac{1}{C2.s}$

$a33 := L3.s + \frac{1}{C3.s} + \frac{1}{C2.s}$

$a34 := -\frac{1}{C3.s}$

$a35 := 0$

$a36 := 0$

$a37 := 0$

$a38 := 0$

$a39 := 0$

$a310 := 0$

$a41 := 0$

$a42 := 0$

$a43 := -\frac{1}{C3.s}$

$a44 := L4.s + \frac{1}{C4.s} + \frac{1}{C3.s}$

$a45 := -\frac{1}{C4.s}$

$a46 := 0$

$a47 := 0$

$a48 := 0$

$a49 := 0$

$a410 := 0$

$a51 := 0$

$a52 := 0$

$a53 := 0$

$a54 := -\frac{1}{C4.s}$

$a55 := L5.s + \frac{1}{C5.s} + \frac{1}{C4.s}$

$a56 := -\frac{1}{C5.s}$

$a57 := 0$

$a58 := 0$

$a59 := 0$

$a510 := 0$

$a61 := 0$

$a62 := 0$

$a63 := 0$

$a64 := 0$

$a65 := -\frac{1}{C5.s}$

$a66 := L6.s + \frac{1}{C6.s} + \frac{1}{C5.s}$

$a67 := -\frac{1}{C6.s}$

$a68 := 0$

$a69 := 0$

$a610 := 0$

$a71 := 0$

$a72 := 0$

$a73 := 0$

$a74 := 0$

$a75 := 0$

$a76 := -\frac{1}{C6.s}$

$a77 := L7.s + \frac{1}{C7.s} + \frac{1}{C6.s}$

$a78 := -\frac{1}{C7.s}$

$a79 := 0$

$a710 := 0$

$a81 := 0$

$a82 := 0$

$a83 := 0$

$a84 := 0$

$a85 := 0$

$a86 := 0$

$a87 := -\frac{1}{C7.s}$

$a88 := L8.s + \frac{1}{C8.s} + \frac{1}{C7.s}$

$a89 := -\frac{1}{C8.s}$

$a810 := 0$

$a91 := 0$

$a92 := 0$

$a93 := 0$

$a94 := 0$

$a95 := 0$

$a96 := 0$

$a97 := 0$

$a98 := -\frac{1}{C8.s}$

$a99 := L9.s + \frac{1}{C9.s} + \frac{1}{C8.s}$

$a910 := -\frac{1}{C9.s}$

$a101 := 0$

$a102 := 0$

$a103 := 0$

$a104 := 0$

$a105 := 0$

$a106 := 0$

$a107 := 0$

$a108 := 0$

$a109 := -\frac{1}{C9.s}$

$a1010 := Rv + \frac{1}{C9.s}$

```
>
  G := matrix(10, 10, [a11, a12, a13, a14, a15, a16,
      a17, a18, a19, a110, a21, a22, a23, a24, a25,
      a26, a27, a28, a29, a210, a31, a32, a33, a34,
      a35, a36, a37, a38, a39, a310, a41, a42, a43,
      a44, a45, a46, a47, a48, a49, a410, a51, a52,
      a53, a54, a55, a56, a57, a58, a59, a510, a61,
      a62, a63, a64, a65, a66, a67, a68, a69, a610,
      a71, a72, a73, a74, a75, a76, a77, a78, a79,
      a710, a81, a82, a83, a84, a85, a86, a87, a88,
      a89, a810, a91, a92, a93, a94, a95, a96, a97,
      a98, a99, a910, a101, a102, a103, a104, a105,
      a106, a107, a108, a109, a1010]);
```

$$G := \left[\left[L1.s + \frac{1}{C1\,s}, -\frac{1}{C1.s}, 0, 0, 0, 0, 0, 0, 0, 0\right],\right.$$
$$\left[-\frac{1}{C1.s}, L2.s + \frac{1}{C2.s} + \frac{1}{C1\,s}, -\frac{1}{C2.s}, 0, 0, 0, 0, 0, 0, 0\right],$$
$$\left[0, -\frac{1}{C2.s}, L3.s + \frac{1}{C3.s} + \frac{1}{C2.s}, -\frac{1}{C3.s}, 0, 0, 0, 0, 0, 0\right],$$
$$\left[0, 0, -\frac{1}{C3.s}, L4.s + \frac{1}{C4.s} + \frac{1}{C3.s}, -\frac{1}{C4.s}, 0, 0, 0, 0, 0\right],$$
$$\left[0, 0, 0, -\frac{1}{C4.s}, L5.s + \frac{1}{C5.s} + \frac{1}{C4.s}, -\frac{1}{C5.s}, 0, 0, 0, 0\right],$$
$$\left[0, 0, 0, 0, -\frac{1}{C5.s}, L6.s + \frac{1}{C6.s} + \frac{1}{C5.s}, -\frac{1}{C6.s}, 0, 0, 0\right],$$
$$\left[0, 0, 0, 0, 0, -\frac{1}{C6.s}, L7.s + \frac{1}{C7.s} + \frac{1}{C6.s}, -\frac{1}{C7.s}, 0, 0\right],$$
$$\left[0, 0, 0, 0, 0, 0, -\frac{1}{C7.s}, L8.s + \frac{1}{C8.s} + \frac{1}{C7.s}, -\frac{1}{C8.s}, 0\right],$$
$$\left[0, 0, 0, 0, 0, 0, 0, -\frac{1}{C8.s}, L9.s + \frac{1}{C9.s} + \frac{1}{C8.s}, -\frac{1}{C9.s}\right],$$
$$\left.\left[0, 0, 0, 0, 0, 0, 0, 0, -\frac{1}{C9.s}, Rv + \frac{1}{C9.s}\right]\right]$$

> $with(linalg) : Gg := inverse(G);$

[Length of output exceeds limit of 1000000]

9-1-2 Finite Element Calculation when System is Divided to 5 Sections:

9-1-2-1 Mathematical Calculation of the Finite Element of Lossless Pipeline when System is divided to 5 Sections symbolically is as below:

$$a11 := L1.s + \frac{1}{C1 \cdot s}; \ a12 := -\frac{1}{C1.s}; \ a13 := 0;$$
$$a14 := 0; \ a15 := 0; \ a16 := 0; \ a21 := -\frac{1}{C1.s};$$
$$a22 := L2.s + \frac{1}{C2.s} + \frac{1}{C1 \cdot s}; \ a23 :=$$
$$-\frac{1}{C2.s}; \ a24 := 0; \ a25 := 0; \ a26 := 0; \ a31$$
$$:= 0; \ a32 := -\frac{1}{C2.s}; \ a33 := L3.s + \frac{1}{C3.s}$$
$$+ \frac{1}{C2.s}; \ a34 := -\frac{1}{C3.s}; \ a35 := 0; \ a36 := 0;$$
$$a41 := 0; \ a42 := 0; \ a43 := -\frac{1}{C3.s}; \ a44 := L4$$
$$.s + \frac{1}{C4.s} + \frac{1}{C3.s}; \ a45 := -\frac{1}{C4.s}; \ a46$$
$$:= 0; \ a51 := 0; \ a52 := 0; \ a53 := 0; \ a54 :=$$
$$-\frac{1}{C4.s}; \ a55 := L5.s + \frac{1}{C5.s} + \frac{1}{C4.s}; \ a56 :=$$
$$-\frac{1}{C5.s}; \ a61 := 0; \ a62 := 0; \ a63 := 0; \ a64$$
$$:= 0; \ a65 := -\frac{1}{C5.s}; \ a66 := \frac{1}{C5.s} + Rv$$

$$a11 := L1.s + \frac{1}{C1\ s}$$

$$a12 := -\frac{1}{C1.s}$$

$$a13 := 0$$

$$a14 := 0$$

$$a15 := 0$$

$$a16 := 0$$

$$a21 := -\frac{1}{C1.s}$$

$$a22 := L2.s + \frac{1}{C2.s} + \frac{1}{C1\ s}$$

$$a23 := -\frac{1}{C2.s}$$

$$a24 := 0$$

$$a25 := 0$$

$$a26 := 0$$

$$a31 := 0$$

$$a32 := -\frac{1}{C2.s}$$

$$a33 := L3.s + \frac{1}{C3.s} + \frac{1}{C2.s}$$

$$a34 := -\frac{1}{C3.s}$$

$$a35 := 0$$

$$a36 := 0$$

$$a41 := 0$$

$$a42 := 0$$

$$a43 := -\frac{1}{C3.s}$$

$$a44 := L4.s + \frac{1}{C4.s} + \frac{1}{C3.s}$$

$$a45 := -\frac{1}{C4.s}$$

$$a46 := 0$$

$$a51 := 0$$

$$a52 := 0$$

$$a53 := 0$$

$$a54 := -\frac{1}{C4.s}$$

$$a55 := L5.s + \frac{1}{C5.s} + \frac{1}{C4.s}$$

$$a56 := -\frac{1}{C5.s}$$

$$a61 := 0$$

$$a62 := 0$$

$$a63 := 0$$

$a64 := 0$

$a65 := -\frac{1}{C5.s}$

$a66 := \frac{1}{C5.s} + Rv$

> G := matrix(6, 6, [*a11*, *a12*, *a13*, *a14*, *a15*, *a16*, *a21*, *a22*, *a23*, *a24*, *a25*, *a26*, *a31*, *a32*, *a33*, *a34*, *a35*, *a36*, *a41*, *a42*, *a43*, *a44*, *a45*, *a46*, *a51*, *a52*, *a53*, *a54*, *a55*, *a56*, *a61*, *a62*, *a63*, *a64*, *a65*, *a66*,]);

$$G := \left[\left[L1.s + \frac{1}{C1\,s}, -\frac{1}{C1.s}, 0, 0, 0, 0\right], \left[-\frac{1}{C1.s}, L2.s + \frac{1}{C2.s} + \frac{1}{C1\,s}, -\frac{1}{C2.s}, 0, 0, 0\right], \left[0, -\frac{1}{C2.s}, L3.s + \frac{1}{C3.s} + \frac{1}{C2.s}, -\frac{1}{C3.s}, 0, 0\right], \left[0, 0, -\frac{1}{C3.s}, L4.s + \frac{1}{C4.s} + \frac{1}{C3.s}, -\frac{1}{C4.s}, 0\right], \left[0, 0, 0, -\frac{1}{C4.s}, L5.s + \frac{1}{C5.s} + \frac{1}{C4.s}, -\frac{1}{C5.s}\right], \left[0, 0, 0, 0, -\frac{1}{C5.s}, \frac{1}{C5.s} + Rv\right]\right]$$

with(*linalg*) : *Gg* := *inverse*(*G*);

F = [*Gg*[1, 1]];

E = [*Gg*[6, 1]];

9-1-2-2 Mathematical Calculation of the Finite Element of Lossless Pipeline when System is divided to 5 Sections numerically is as below:

> *L1* := *9.3574e* − 4; *L2* := *L1*; *L3* := *L1*; *L4* := *L1*; *L5* := *L1*; *L6* := *L1*; *C1* := *2.79086e*−*7*; *C2* := *C1*; *C3* := *C1*; *C4* := *C1*; *C5* := *C1*; *C6* := *C1*; *Rv* := 10.612;

$L1 := 9.3574\,e - 4$

$L2 := 9.3574\,e - 4$

$L3 := 9.3574\,e - 4$

$L4 := 9.3574\,e - 4$

$L5 := 9.3574\,e - 4$

$L6 := 9.3574\,e - 4$

$C1 := 2.79086\ 10^{-7}$

$C2 := 2.79086\ 10^{-7}$

$C3 := 2.79086\ 10^{-7}$

$C4 := 2.79086\ 10^{-7}$

$C5 := 2.79086\ 10^{-7}$

$C6 := 2.79086\ 10^{-7}$

$Rv := 10.612$

>

$$a11 := L1.s + \frac{1}{C1 \cdot s};\ a12 := -\frac{1}{C1.s};\ a13 := 0;\ a14 := 0;\ a15 := 0;\ a16 := 0;\ a21 := -\frac{1}{C1.s};\ a22 := L2.s + \frac{1}{C2.s} + \frac{1}{C1 \cdot s};\ a23 := -\frac{1}{C2.s};\ a24 := 0;\ a25 := 0;\ a26 := 0;\ a31 := 0;\ a32 := -\frac{1}{C2.s};\ a33 := L3.s + \frac{1}{C3.s} + \frac{1}{C2.s};\ a34 := -\frac{1}{C3.s};\ a35 := 0;\ a36 := 0;\ a41 := 0;\ a42 := 0;\ a43 := -\frac{1}{C3.s};\ a44 := L4.s + \frac{1}{C4.s} + \frac{1}{C3.s};\ a45 := -\frac{1}{C4.s};\ a46 := 0;\ a51 := 0;\ a52 := 0;\ a53 := 0;\ a54 := -\frac{1}{C4.s};\ a55 := L5.s + \frac{1}{C5.s} + \frac{1}{C4.s};\ a56 := -\frac{1}{C5.s};\ a61 := 0;\ a62 := 0;\ a63 := 0;\ a64 := 0;\ a65 := -\frac{1}{C5.s};\ a66 := \frac{1}{C5.s} + Rv;$$

$$a11 := (9.3574\,e - 4).s + \frac{3.583124915\ 10^{6}}{s}$$

$a12 := -\frac{3.583124915\ 10^6}{s}$

$a13 := 0$

$a14 := 0$

$a15 := 0$

$a16 := 0$

$a21 := -\frac{3.583124915\ 10^6}{s}$

$a22 := (9.3574\ e - 4).s + \frac{7.166249830\ 10^6}{s}$

$a23 := -\frac{3.583124915\ 10^6}{s}$

$a24 := 0$

$a25 := 0$

$a26 := 0$

$a31 := 0$

$a32 := -\frac{3.583124915\ 10^6}{s}$

$a33 := (9.3574\ e - 4).s + \frac{7.166249830\ 10^6}{s}$

$a34 := -\frac{3.583124915\ 10^6}{s}$

$a35 := 0$

$a36 := 0$

$a41 := 0$

$a42 := 0$

$a43 := -\frac{3.583124915\ 10^6}{s}$

$a44 := (9.3574\ e - 4).s + \frac{7.166249830\ 10^6}{s}$

$a45 := -\frac{3.583124915\ 10^6}{s}$

$a46 := 0$

$a51 := 0$

$a52 := 0$

$a53 := 0$

$a54 := -\frac{3.583124915\ 10^{6}}{s}$

$a55 := (9.3574\, e - 4).s + \frac{7.166249830\ 10^{6}}{s}$

$a56 := -\frac{3.583124915\ 10^{6}}{s}$

$a61 := 0$

$a62 := 0$

$a63 := 0$

$a64 := 0$

$a65 := -\frac{3.583124915\ 10^{6}}{s}$

$a66 := \frac{3.583124915\ 10^{6}}{s} + 10.612$

```
> G := matrix(6, 6, [a11, a12, a13, a14, a15, a16,
    a21, a22, a23, a24, a25, a26, a31, a32, a33,
    a34, a35, a36, a41, a42, a43, a44, a45, a46,
    a51, a52, a53, a54, a55, a56, a61, a62, a63,
    a64, a65, a66]);
```

$$G := \left[\left[(9.3574\,e-4).s+\frac{3.583124915\ 10^{6}}{s},\right.\right.$$
$$\left.-\frac{3.583124915\ 10^{6}}{s},0,0,0,0\right],$$
$$\left[-\frac{3.583124915\ 10^{6}}{s},(9.3574\,e-4).s\right.$$
$$+\frac{7.166249830\ 10^{6}}{s},-\frac{3.583124915\ 10^{6}}{s},0,0,0$$
$$\left.\right],$$
$$\left[0,-\frac{3.583124915\ 10^{6}}{s},(9.3574\,e-4).s\right.$$
$$\left.+\frac{7.166249830\ 10^{6}}{s},-\frac{3.583124915\ 10^{6}}{s},0,0\right],$$
$$\left[0,0,-\frac{3.583124915\ 10^{6}}{s},(9.3574\,e-4).s\right.$$
$$\left.+\frac{7.166249830\ 10^{6}}{s},-\frac{3.583124915\ 10^{6}}{s},0\right],$$
$$\left[0,0,0,-\frac{3.583124915\ 10^{6}}{s},(9.3574\,e-4).s\right.$$
$$\left.+\frac{7.166249830\ 10^{6}}{s},-\frac{3.583124915\ 10^{6}}{s}\right],$$
$$\left[0,0,0,0,-\frac{3.583124915\ 10^{6}}{s},\frac{3.583124915\ 10^{6}}{s}\right.$$
$$\left.\left.+10.612\right]\right]$$

> $with(linalg) : Gg := inverse(G);$

$F = [Gg[1, 1]];$

$E = [Gg[6, 1]];$

9-1-2-3 Mathematical Calculation of the Finite Element of lossy pipeline when System is Divided to 5 Sections Symbolically is as below:

> $Z_R := Ls + R;$

$Z_R := Ls + R$

> $Z_G := \dfrac{G}{C.G.s + 1};$

$Z_G := \dfrac{G}{C.s.G + 1}$

> $M := \dfrac{Z_G.Z_R}{Z_R + Z_G};$

$$M := \frac{\left(\frac{G}{C.s.G + 1}\right).(Ls + R)}{Ls + R + \frac{G}{C.s.G + 1}}$$

$$a11 := \frac{\left(\frac{G1}{C1.s.G1+1}\right).(L1.s+R1)}{L1.s+R1+\frac{G1}{C1.s.G1+1}}; a12 := -\frac{G1}{C1.s.G1+1}; a13 := 0; a14 := 0; a15 := 0; a16 := 0; a21 := -\frac{G1}{C1.G1+1}; a22 := \frac{\left(\frac{G2}{C2.s.G2+1}\right).(L2.s+R2)}{L2.s+R2+\frac{G2}{C2.s.G2+1}} + \frac{G1}{C1.G1.s+1}; a23 := -\frac{G2}{C2.G2.s+1}; a24 := 0; a25 := 0; a26 := 0; a31 := 0; a32 := -\frac{G2}{C2.s.G2+1}; a33 := \frac{\left(\frac{G3}{C3.s.G3+1}\right).(L3.s+R3)}{L3.s+R3+\frac{G3}{C3.s.G3+1}} + \frac{G2}{C2.s.G2+1}; a34 := -\frac{G3}{C3.s.G3+1}; a35 := 0; a36 := 0; a41 := 0; a42 := 0; a43 := -\frac{G3}{C3.s.G3+1}; a44 := \frac{\left(\frac{G4}{C4.s.G4+1}\right).(L4.s+R4)}{L4.s+R4+\frac{G4}{C4.s.G4+1}} + \frac{G3}{C3.s.G3+1}; a45 := -\frac{G4}{C4.s.G4+1}; a46 := 0; a51 := 0; a52 := 0; a53 := 0; a54 := -\frac{G4}{C4.s.G4+1}; a55 := \frac{\left(\frac{G5}{C5.s.G5+1}\right).(L5.s+R5)}{L5.s+R5+\frac{G5}{C5.s.G5+1}} + \frac{G4}{C4.s.G4+1}; a56 := -\frac{G5}{C5.s.G5+1}; a61 := 0; a62 := 0; a63 := 0; a64 := 0; a65 := -\frac{G5}{C5.s.G5+1}; a66 := R_v + \frac{G5}{C5.s.G5+1};$$

$$a11 := \frac{\left(\frac{G1}{C1.s.G1 + 1}\right).(L1.s + R1)}{L1.s + R1 + \frac{G1}{C1.s.G1 + 1}}$$

$$a12 := -\frac{G1}{C1.s.G1 + 1}$$

$$a13 := 0$$

$$a14 := 0$$

$$a15 := 0$$

$$a16 := 0$$

$$a21 := -\frac{G1}{C1.G1 + 1}$$

$$a22 := \frac{\left(\frac{G2}{C2.s.G2 + 1}\right).(L2.s + R2)}{L2.s + R2 + \frac{G2}{C2.s.G2 + 1}} + \frac{G1}{C1.G1.s + 1}$$

$$a23 := -\frac{G2}{C2.G2.s + 1}$$

$$a24 := 0$$

$$a25 := 0$$

$$a26 := 0$$

$$a31 := 0$$

$$a32 := -\frac{G2}{C2.s.G2 + 1}$$

$$a33 := \frac{\left(\frac{G3}{C3.s.G3 + 1}\right).(L3.s + R3)}{L3.s + R3 + \frac{G3}{C3.s.G3 + 1}} + \frac{G2}{C2.s.G2 + 1}$$

$$a34 := -\frac{G3}{C3.s.G3 + 1}$$

$$a35 := 0$$

$$a36 := 0$$

$a41 := 0$

$a42 := 0$

$a43 := -\frac{G3}{C3.s.G3 + 1}$

$$a44 := \frac{\left(\frac{G4}{C4.s.G4 + 1}\right).(L4.s + R4)}{L4.s + R4 + \frac{G4}{C4.s.G4 + 1}} + \frac{G3}{C3.s.G3 + 1}$$

$a45 := -\frac{G4}{C4.s.G4 + 1}$

$a46 := 0$

$a51 := 0$

$a52 := 0$

$a53 := 0$

$a54 := -\frac{G4}{C4.s.G4 + 1}$

$$a55 := \frac{\left(\frac{G5}{C5.s.G5 + 1}\right).(L5.s + R5)}{L5.s + R5 + \frac{G5}{C5.s.G5 + 1}} + \frac{G4}{C4.s.G4 + 1}$$

$a56 := -\frac{G5}{C5.s.G5 + 1}$

$a61 := 0$

$a62 := 0$

$a63 := 0$

$a64 := 0$

$a65 := -\frac{G5}{C5.s.G5 + 1}$

$a66 := R_v + \frac{G5}{C5.s.G5 + 1}$

>

$G := \mathrm{matrix}(6, 6, [a11, a12, a13, a14, a15, a16,$
$a21, a22, a23, a24, a25, a26, a31, a32, a33,$
$a34, a35, a36, a41, a42, a43, a44, a45, a46,$
$a51, a52, a53, a54, a55, a56, a61, a62, a63,$
$a64, a65, a66]);$

$$G := \left[\left[\frac{\left(\frac{G1}{C1.s.G1+1}\right).(L1.s+R1)}{L1.s+R1+\frac{G1}{C1.s.G1+1}}, -\frac{G1}{C1.s.G1+1}, 0, 0, 0, 0\right], \left[-\frac{G1}{C1.G1+1}, \frac{\left(\frac{G2}{C2.s.G2+1}\right).(L2.s+R2)}{L2.s+R2+\frac{G2}{C2.s.G2+1}} + \frac{G1}{C1.G1.s+1}, -\frac{G2}{C2.G2.s+1}, 0, 0, 0\right], \left[0, -\frac{G2}{C2.s.G2+1}, \frac{\left(\frac{G3}{C3.s.G3+1}\right).(L3.s+R3)}{L3.s+R3+\frac{G3}{C3.s.G3+1}} + \frac{G2}{C2.s.G2+1}, -\frac{G3}{C3.s.G3+1}, 0, 0\right], \left[0, 0, -\frac{G3}{C3.s.G3+1}, \frac{\left(\frac{G4}{C4.s.G4+1}\right).(L4.s+R4)}{L4.s+R4+\frac{G4}{C4.s.G4+1}} + \frac{G3}{C3.s.G3+1}, -\frac{G4}{C4.s.G4+1}, 0\right], \left[0, 0, 0, -\frac{G4}{C4.s.G4+1}, \frac{\left(\frac{G5}{C5.s.G5+1}\right).(L5.s+R5)}{L5.s+R5+\frac{G5}{C5.s.G5+1}} + \frac{G4}{C4.s.G4+1}, -\frac{G5}{C5.s.G5+1}\right], \left[0, 0, 0, 0, -\frac{G5}{C5.s.G5+1}, R_v + \frac{G5}{C5.s.G5+1}\right]\right]$$

$with(linalg) : Gg := inverse(G);$

$F = [Gg[1, 1]];$

$E = [Gg[6, 1]];$

9-1-2-4 Mathematical Calculation of the Finite Element of Lossy Pipeline when System is Divided to 5 Sections Numerically is as below:

$>$ $L1 := 9.3574\text{e}-4; L2 := L1; L3 := L1; L4 := L1; L5 := L1; L6 := L1; C1 := 2.79086e-7; C2 := C1; C3 := C1; C4 := C1; C5 := C1; C6 := C1; G1 := 2.543e-6; G2 := G1; G3 := G1; G4 := G1; G5 := G1; G6 := G1; R1 := 0.0001; R2 := R1; R3 := R1; R4 := R1; R5 := R1; R6 := R1; R_v := 10.612;$

$L1 := 0.00093574$

$L2 := 0.00093574$

$L3 := 0.00093574$

$L4 := 0.00093574$

$L5 := 0.00093574$

$L6 := 0.00093574$

$C1 := 2.79086\ 10^{-7}$

$C2 := 2.79086\ 10^{-7}$

$C3 := 2.79086\ 10^{-7}$

$C4 := 2.79086\ 10^{-7}$

$C5 := 2.79086\ 10^{-7}$

$C6 := 2.79086\ 10^{-7}$

$G1 := 0.000002543$

$G2 := 0.000002543$

$G3 := 0.000002543$

$G4 := 0.000002543$

$G5 := 0.000002543$

$G6 := 0.000002543$

$R1 := 0.0001$

$R2 := 0.0001$

$R3 := 0.0001$

$R4 := 0.0001$

$R5 := 0.0001$

$R6 := 0.0001$

$R_v := 10.612$

$$a11 := \frac{\left(\frac{G1}{C1.s.G1 + 1}\right).(L1.s + R1)}{L1.s + R1 + \frac{G1}{C1.s.G1 + 1}};\ a12 := -\frac{G1}{C1.s.G1 + 1};\ a13 := 0;\ a14 := 0;\ a15 := 0;\ a16 := 0;\ a21 := -\frac{G1}{C1.G1 + 1};$$

$$a22 := \frac{\left(\frac{G2}{C2.s.G2 + 1}\right).(L2.s + R2)}{L2.s + R2 + \frac{G2}{C2.s.G2 + 1}} + \frac{G1}{C1.G1.s + 1};\ a23 := -\frac{G2}{C2.G2.s + 1};\ a24 := 0;\ a25 := 0;\ a26 := 0;\ a31 := 0;\ a32 := -\frac{G2}{C2.s.G2 + 1};$$

$$a33 := \frac{\left(\frac{G3}{C3.s.G3 + 1}\right).(L3.s + R3)}{L3.s + R3 + \frac{G3}{C3.s.G3 + 1}} + \frac{G2}{C2.s.G2 + 1};\ a34 := -\frac{G3}{C3.s.G3 + 1};\ a35 := 0;\ a36 := 0;\ a41 := 0;\ a42 := 0;\ a43 := -\frac{G3}{C3.s.G3 + 1};$$

$$a44 := \frac{\left(\frac{G4}{C4.s.G4 + 1}\right).(L4.s + R4)}{L4.s + R4 + \frac{G4}{C4.s.G4 + 1}} + \frac{G3}{C3.s.G3 + 1};\ a45 := -\frac{G4}{C4.s.G4 + 1};\ a46 := 0;\ a51 := 0;\ a52 := 0;\ a53 := 0;\ a54 := -\frac{G4}{C4.s.G4 + 1};$$

$$a55 := \frac{\left(\frac{G5}{C5.s.G5 + 1}\right).(L5.s + R5)}{L5.s + R5 + \frac{G5}{C5.s.G5 + 1}} + \frac{G4}{C4.s.G4 + 1};\ a56 := -\frac{G5}{C5.s.G5 + 1};\ a61 := 0;\ a62 := 0;\ a63 := 0;\ a64 := 0;\ a65 := -\frac{G5}{C5.s.G5 + 1};\ a66 := R_v + \frac{G5}{C5.s.G5 + 1};$$

$$a11 := \left(0.000002543 \left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right).(0.00093574\ s + 0.0001)\right)\right) \Big/ \left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right)$$

$$a12 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a13 := 0$$

$$a14 := 0$$

$$a15 := 0$$

$$a16 := 0$$

$$a21 := -0.000002543000000$$

$$a22 := \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right) .(0.00093574\ s + 0.0001)\right)\right) \Big/ \left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right) + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a23 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a24 := 0$$

$$a25 := 0$$

$$a26 := 0$$

$$a31 := 0$$

$$a32 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a33 := \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right) .(0.00093574\ s + 0.0001)\right)\right) \Big/ \left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right) + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a34 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a35 := 0$$

$a36 := 0$

$a41 := 0$

$a42 := 0$

$$a43 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a44 := \left(0.000002543 \left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right) .(0.00093574\ s + 0.0001)\right)\right) \Big/ \left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right) + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a45 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$a46 := 0$

$a51 := 0$

$a52 := 0$

$a53 := 0$

$$a54 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a55 := \left(0.000002543 \left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right) .(0.00093574\ s + 0.0001)\right)\right) \Big/ \left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right) + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a56 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$a61 := 0$

$a62 := 0$

$a63 := 0$

$a64 := 0$

$$a65 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a66 := 10.612 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

> G := matrix(6, 6, [*a11*, *a12*, *a13*, *a14*, *a15*, *a16*, *a21*, *a22*, *a23*, *a24*, *a25*, *a26*, *a31*, *a32*, *a33*, *a34*, *a35*, *a36*, *a41*, *a42*, *a43*, *a44*, *a45*, *a46*, *a51*, *a52*, *a53*, *a54*, *a55*, *a56*, *a61*, *a62*, *a63*, *a64*, *a65*, *a66*]);

$$a11 := \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right) .(0.00093574\ s + 0.0001)\right)\right) \Big/ \left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right)$$

$$a12 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$a13 := 0$

$a14 := 0$

$a15 := 0$

$a16 := 0$

$a21 := -0.000002543000000$

$$a22 := \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right) .(0.00093574\ s + 0.0001)\right)\right) \Big/ \left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right) + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a23 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$a24 := 0$

$a25 := 0$

$a26 := 0$

$a31 := 0$

$$a32 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a33 := \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right).(0.00093574\ s + 0.0001)\right)\right)\Bigg/\left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right) + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a34 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$a35 := 0$

$a36 := 0$

$a41 := 0$

$a42 := 0$

$$a43 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a44 := \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right).(0.00093574\ s + 0.0001)\right)\right)\Bigg/\left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right) + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a45 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$a46 := 0$

$a51 := 0$

$a52 := 0$

$a53 := 0$

$$a54 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a55 := \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s + 1}\right) .(0.00093574\ s + 0.0001)\right)\right) \Big/ \left(0.00093574\ s + 0.0001 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}\right) + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a56 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a61 := 0$$

$$a62 := 0$$

$$a63 := 0$$

$$a64 := 0$$

$$a65 := -\frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$$a66 := 10.612 + \frac{0.000002543}{7.09715698\ 10^{-13}\ s + 1}$$

$G := \text{matrix}(6, 6, [a11, a12, a13, a14, a15, a16, a21, a22, a23, a24, a25, a26, a31, a32, a33, a34, a35, a36, a41, a42, a43, a44, a45, a46, a51, a52, a53, a54, a55, a56, a61, a62, a63, a64, a65, a66]);$

$$G := \Bigg[\Bigg[\left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s+1}\right).(0.00093574\ s+0.0001)\right)\right)\Bigg/\left(0.00093574\ s+0.0001+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}\right), -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, 0, 0, 0, 0\Bigg],$$

$$\Bigg[-0.000002543000000, \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s+1}\right).(0.00093574\ s+0.0001)\right)\right)\Bigg/\left(0.00093574\ s+0.0001+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}\right)+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, 0, 0, 0\Bigg],$$

$$\Bigg[0, -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s+1}\right).(0.00093574\ s+0.0001)\right)\right)\Bigg/\left(0.00093574\ s+0.0001+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}\right)+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, 0, 0\Bigg],$$

$$\Bigg[0, 0, -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s+1}\right).(0.00093574\ s+0.0001)\right)\right)\Bigg/\left(0.00093574\ s+0.0001+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}\right)+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, 0\Bigg],$$

$$\Bigg[0, 0, 0, -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, \left(0.000002543\left(\left(\frac{1}{7.09715698\ 10^{-13}\ s+1}\right).(0.00093574\ s+0.0001)\right)\right)\Bigg/\left(0.00093574\ s+0.0001+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}\right)+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}\Bigg],$$

$$\Bigg[0, 0, 0, 0, -\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}, 10.612+\frac{0.000002543}{7.09715698\ 10^{-13}\ s+1}\Bigg]\Bigg]$$

$with(linalg) : Gg := inverse(G);$

$F = [Gg[1, 1]];$

$E = [Gg[6, 1]];$

9-2: MATLAB Bode Diagram Commands with Two T and two τ

```
>> num=[0.93574,1];

>> den=[0.10974,1];

>> sys=tf(num,den);

>> bode(sys)

hold

Current plot held

>> T1=1/0.999;T2=1/3.82;Tu1=1/1.5,Tu2=1/7.43;

Tu1 =

    0.6667

>> A=[T1,1];B=[T2,1];C=[Tu1,1];D=[Tu2,1];

>> AA=conv(A,A)


AA =

    1.0020    2.0020    1.0000

>> BB=conv(B,B);CC=conv(C,C);DD=conv(D,D);

>> num=conv(AA,BB);Den=conv(CC,DD);

>> sys=tf(num,Den)
```

Transfer function:

0.06867 s^4 + 0.6618 s^3 + 2.119 s^2 + 2.526 s + 1

0.008051 s^4 + 0.1438 s^3 + 0.8215 s^2 + 1.603 s + 1

>> bode(sys)

9-3: Pressure- Temperature Rating

According to ASME B16.34, STD Class of Valves with Grade CF3 and ASTM A351

TEMPERATURE	WORKING PRESSURES BY CLASS				
	150	300	600	900	1500
°F	Psig				
−20 to 100	275	720	1,440	2,160	3,600
200	230	600	1,200	1,800	3,000
300	205	540	1,080	1,620	2,700
400	190	495	995	1,490	2,485
500	170	465	930	1,395	2,330
600	140	435	875	1,310	2,185
650	125	430	860	1,290	2,150
700	110	425	850	1,275	2,125
750	95	415	830	1,245	2,075
800	80	405	805	1,210	2,015
850	65	395	790	1,190	1,980
900	50	390	780	1,165	1,945
950	35	380	765	1,145	1,910
1000	20	320	640	965	1,605
1050	20(1)	310	615	925	1,545
1100	20(1)	255	515	770	1,285
1150	20(1)	200	400	595	995
1200	20(1)	155	310	465	770
1250	20(1)	115	225	340	565
1300	20(1)	85	170	255	430
1350	20(1)	60	125	185	310
1400	20(1)	50	95	145	240
1450	15(1)	35	70	105	170
1500	10(1)	25	55	80	135
°C	Bar				
−29 to 38	19	50	99	149	248
93	16	41	83	124	207
149	14	37	74	112	186
204	13	34	69	103	171
260	12	32	64	96	161
316	10	30	60	90	151
343	9	30	59	89	148
371	8	29	59	88	147
399	7	29	57	86	143
427	6	28	56	83	139

TEMPERATURE	WORKING PRESSURES BY CLASS				
	150	300	600	900	1500
°C	Bar				
454	4	27	54	82	137
482	3	27	54	80	134
510	2	26	53	79	132
538	1	22	44	67	111
565	1(1)	21	42	64	107
593	1(1)	18	36	53	89
621	1(1)	14	28	41	69
649	1(1)	11	21	32	53
676	1(1)	8	16	23	39
704	1(1)	6	12	18	30
732	1(1)	4	9	13	21
760	1(1)	3	7	10	17
788	1(1)	2	5	70	12
815	1(1)	2	4	6	9

1. For welding end valves only. Flanged end ratings terminate at 1000°F.

Figure (9-1) Underground large pipelines