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Root locus theory in active vibration control system of pipes conveying fluid rested on different supports

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Abstract
In spite of this widespread and critical importance of fluid conveying pipes, they suffer from major problems. One of these problems is the problem of vibrations that cause the collapse of the systems completely and cause significant economic losses if not avoided. Where, fluid conveying pipes are used in all hydraulic systems and enter in all industrial fields, such as water, petroleum products and gases of all kinds. For this reason, the researchers have dealt with this issue in all years, but the problem is not over. This research will highlight the problem of controlling the vibrations resulting from fluid flow inside the pipes, in addition to the study of reducing the vibrations of these pipes. This study is carried out by deriving differential equations for pipes and for different types of fixation. The research has studied the response and the natural frequency; the dynamic behavior of different types of stabilization of the pipes in the presence with no hydraulic damping (active control); and monitoring the response and stability of each case of stabilization. Where, in this paper using root locus technique to calculate the control for pipe conveying fluid. Thus, the investigation included calculated the effect for different damper parameters and fluid on the pipe stability. There, this work is expansion for previous study investigated the control for pipe vibration with using other stability and control theories, and comparison for presenting results with previous results, therefore, form comparison results found that the loot locus technique is a good technique can be using to investigation the stability and control for pipe fluid.

Keywords: Active vibration control; pipe conveying fluid; root locus theory; paths of the roots; root locus characteristic equation; multiple input and output systems.

1. Introduction

Roundabout and noncircular liquid stream in pipes is every now and again experienced by and by. The cold and heated water utilized in our homes is siphoned in through the channels. Tap water in a city is spread out through broad systems of funneling. By huge pipelines gaseous petrol and oil stream around many miles a similar way blood is conveyed all through our bodies by veins and conduits. A similar way, the cooling water in a machine or a motor streams by hoses into the channels, it is cooled as it streams in the radiator. In the arrangement of hydronic space warming, warm vitality is moved to the flowed water in a kettle; a short time later, it is moved to the target areas into pipes. Liquid stream could be either inner or outer, according to whether the liquid is upheld to stream in a conductor or over a surface. External and inner streams show totally different properties. In this part internal stream is considered, where the channel is completely loaded up with liquid, and primarily, stream is essentially determined by pressure contrast.

This procedure isn't being bewildered with open channel stream technique where in part, the liquid fills the conduit and in this way the stream is confined somewhat by strong surfaces, as on account of a irrigation dump, and, thusly, gravity is the main power that drives the flow, [1].

At 1970 R. A. Stein et. al., [2], developed the equation of motion for pipelines of infinite length fluids that controlled and transported ideally. They explained the internal pressure forces of the fluid-carrying pipes, the effect of the coefficient of foundation, response, velocity characteristics and wave propagation of the non-damping system. When the fluid does not exceed critical velocity, the system is in a stable state. The flow has two important effects. First, it reduces oscillate but the frequency difference will increase. The vibration of clamped and simply ends infinitely pipe whereas pressure decreases the observed frequency of the system. Also at 2001, X. Wang et. al., [3], studied the static and dynamic instabilities of submerged and inclined concentrically pipes transporting fluid. The equation governing the interior hollow beam was by-product below the tiny deformational assumption. They earned the dynamic discretized equations employing schemes of abstraction finite-difference. In steady flow, each buckling and flutter instabilities were examined.

Then at 2002, O. Doare et. al., [4], created the relationship between the global and local motions of bending for fluid pipes conveying on a flexible floor or elastic foundation. The process of global imposed a pipe of finite with a given collection of boundary conditions, while in the process of local it referred to a pipe which has infinite length with a note without taking in consideration its finite ends. Various kinds of diffusion disturbances are specific from the relation of dispersion, namely evanescent, unstable and neutral waves, such as the pipe length which is increased, the global base for instability which is established to coincide with the neutrality of local, by dint of neutral waves generated only a local harmonic impact. Also, the collection of boundary conditions give lift only to instabilities of static. The process for global instability of the very long pipe is neutral static waves present. Contrariwise, for the collection of boundary conditions which permit dynamic instabilities, the process for global instability of the very long pipe is compatible for the presence of indifferent waves of nonzero finite frequency. These results are discussed in a relationship with the theory of Kulikovskii work and another comparable process in the theory of hydrodynamic stability.

Also at 2010, M. R. Xu et. al., [5], the homotopy perturbation method was used in this study to derived candor for the natural frequencies of pipes conveying fluid with pinned- pinned boundary condition which are in a straightforward and systematical manner. Numerical results are offered for two cases and the natural frequencies are shown because of the effective influence of fluid flow velocity. Good deal with their empirical and FEM rival is located numerically above the ranges of practical benefit. It was also found in this research that the increase of the inside fluid velocity leads to the natural frequencies of the pipe decrease. Also, it can be seen that the theoretical results for this research agree perfectly with their numerical and experimental rivals with a difference that includes 10% because the flow velocity is far than the critical point. In this research, an alternative process to commonly used methods, complex mode process and Galerkin method, is submitted to survey the natural frequencies of pipes fluid conveying. This suggests a specific method characteristic when compared with other known methods. Specifically, the suggested process capable a solution represented in a forthright analytical form that does not want a numerical solution of every equation governing the frequencies analytical supreme.

At 2013, T. Szmidt et. al., [6], studied the effect of damping on the system of dynamic for pipe conveying fluid. They took three stabilization cases: clamped-clamped, cantilever and simply supported pipe. They assumed physiological parameters to the system that allows for practical results. They also assumed a fully advanced turbulent flow that may be approached by the named plug flow for associate infinite elastic of rod is affected internal the pipe. They developed easy strategies during which internal and external damping coefficients are calculated per the bottom of the known models. The partial equation governing the description is with Galerkin's procedure. The stability of the consequent dynamical of the system was verified at eigenvalues of it is linearization. The actuators of destabilizing for pipe supported at both ends, but will noticeable progress stability for cantilever very. The influence of magnetic damping highly depends on the position or situation of the actuators measure hold off to the pipe. And reached to reduce the gap in the magnetic of circuits upgrades the potency this the tactic. The destabilization of each studied pipes happens at the flow velocities square measure very high.

Also, at 2014, N. H. Mostafa, [7], studied a simply supported conveyor pipe (a hinge type) with a stable incompressible fluid. This pipe is placed on a viscoelastic foundation and analyzed using a finite element with critical fluid velocity in various parameters such as viscous coefficients and stiffness of the foundation. The foundation was analyzed using the modified Winkler's model. Some known results have been confirmed and some new results have been obtained. He noted that two components of the foundation; viscosity and stiffness, affect the velocity of critical fluid moving inside the pipe in the opposite direction. The increased viscosity of the foundation leads to a decrease in the flow of fluid inside the pipe while increasing the stiffness of the foundation leads to increased flow. For some ranges of pipe lengths, the viscosity factors are more influential. The increased flow velocity also leads to a monotonous reduction in the damping ratio.

At 2015 M. J. Jweeg et. al., [8], investigated the closed and open loop time responses to the active vibration concerning the smart cantilever pipe fluid conveying as a simulation and an experimental study of active vibrations. A program has been designed to simulate the lowering of active vibration of pipe stiffened with actuators and piezoelectric sensors in ANSYS. The language of parametric design is (APDL). This use makes the ability of finite element for the ANSYS program and it includes an amount based on the optimal control of linear quadratic named (LQR) schemes to investigate the closed and open loop time responses. Charts are used to investigate the closed and open loop time responses. The technique is tested through the active control for forced and free vibrations of the smart cantilever piezoelectric for pipe fluid conveying. The forced vibration is considered a harmonic excitation. The simulation was used to conduct and verify experiments. Smart pipes are formed from pipe surface agglutinant piezoelectric splatter of transducers quick pack QP20W. An experiential result was obtained by programs of Lab VIEW. The effectiveness on the response of the system cantilever pipe is due to the position of the actuator piezoelectric. When the actuators are transferred nearer to the clamp, a highest displacement is obtained. The reason is due to the higher strain construct approach of the clamped. The performance of control recedes at increasing the velocity of flow because of raise Coriolis force. The best effect of control happens at a minimum speed discharge =10L/ min. The position of the actuator, extreme drop the response of displacement ranges from (8) mm to (1) mm. also, at same year, same researchers, [9], presenting investigation of control for pipe conveying fluid by using piezoelectric actuators. Where, the investigation included analytical and experimental techniques to control of pipe structure. Thus, the experimental part included manufacturing of actuators to control on the pipe vibration with various flow parameters effect. In addition investigation analytically and experimentally of dynamic behavior for pipe conveying fluid with various parameters effect, [10]. Thus, this investigation included manufactured for vibration rig to calculated the dynamic behavior for pipe by using vibration test machine, in addition to, using the analytical solution for general equation of motion for pipe conveying fluid and calculated the dynamic behavior for pipe, and then comparison the results together.

Then, at 2017, M. J. Jweeg et. al., [11], investigated the dynamic behavior for pipe conveying fluid with various crack effect. Where, the investigation included using experimental and analytical technique to calculate the natural frequency for pipe with crack depth and location effect. Thus, the analytical work included drive for the general equation of motion and solved its equation for simply supported pipe, and then, comparison the results calculated with experimental results calculated. After this, at 2018 S. N. Alnomani, [12], the finite element method used in this study was utilized to analyze the dynamic stability of the fluid-carrying pipe, which was changed in stiffness by the internal flow of the fluid and by the linear spring. Multiple effective parameters of great importance that play a key role in determining the stability, for example, the effect of location for the spring along the pipe in different locations and the effect of increased linear stiffness of the spring and the study of the proportion of diameters as well. Also taking into account the flow velocity over the stability of the system. Also concluded that the constant of spring at this dynamic behavior becomes widely for sensitive and the spring gives good results to the system with respect to its frequencies. The preferred location of the spring depends on the velocity of flow inside the pipe and also depends on the spring constant.

Finally, at 2019, D. S. Hussein et. al., [13, 14], analysis for control vibration of pipe conveying fluid by using state space, [13], and bode diagram technique, [14]. Thus, the investigation included analysis for dynamic behaviour for pipe induce vibration with different supported, and then, drive the general equation of motion for vibration pipe, and finally, solution for its equation and calculating the dynamic response for pipe with different flow parameters effect. Where, the technique used to analysis the dynamic behaviour for pipe was analytical solution by state space technique to analysis the pipe response, [13], and the bode diagram technique to calculated the stability for pipe with various parameters effect, [14]. Therefore, in this paper, investigation the effect for active damper parameters and different flow parameters on the pipe control by using root locus technique by solution the general equation of motion analytically of pipe conveying fluid with different boundary condition. In addition, comparison the results calculated together with previous results calculated, [13, 14].

2. Analytical Investigation

Analytical solution for dynamic behavior for control pipe conveying fluid included evaluated the pipe stability with different damper and flow parameters effect. There, the solution for pipe vibration control required drive the general equation of motion for pipe, and then, applied the boundary condition for pipe, then, solution for its equation by using selected stability method, [15-17]. Therefore, analytical of investigation of the dynamical behavior of pipe conveying fluid will be given, where will examine the equations of the pipes, will take the channels in various sorts of installation and will apply the limit states of each limit according to the establishment. In this work utilize differential conditions for the vibration of pipes. So as to conduct an overall investigation into the dynamic behavior of pipes conveying fluid, a lot of solutions will be attempted. Based on former researchers, the task will focus on the analyses of the stability of the zero balance status of fluid conveying pipes under pulsating flow. The equations were modified utilizing the Matlab and discovering results. When the critical velocity is bigger than the average velocity, or $u_{cr} > u_0$, matrix S owns two pairs from eigenvalues (pure imaginary). Note that u_{cr}, critical velocity, with term,

$$u_{cr} = \sqrt{\left(T + \frac{1}{2}\bar{g} + \frac{-(c_{11}\lambda_2^4 + c_{22}\lambda_1^4) + \sqrt{(c_{11}\lambda_2^4 - c_{22}\lambda_1^4)^2 + 4c_{11}c_{22}\bar{g}^2e^2}}{2c_{11}c_{22}}\right)} \quad (1)$$

In case of negligence, the preload and gravity u_{cr} will be simplified as follows,

$$u_{cr}^2 = -\frac{\lambda_1^4}{c_{11}} \Rightarrow u_{cr} = \sqrt{-\frac{\lambda_1^4}{c_{11}}} = \begin{cases} \pi i & p-p \\ 6.38i & c-c \end{cases}$$

If, assume $\pm\Omega_1 i, \pm\Omega_2 i$ as eigenvalues of matrix S, that would be,

$$U^{-1}SU = \begin{pmatrix} \Omega_1 i & 0 & 0 & 0 \\ 0 & -\Omega_1 i & 0 & 0 \\ 0 & 0 & \Omega_2 i & 0 \\ 0 & 0 & 0 & -\Omega_2 i \end{pmatrix} \quad (2)$$

Ω_1 and Ω_2 are the natural frequencies of fluid conveying pipes vibrations within the velocity of steady flow. U is a matrix with eigenvectors with relative eigenvalues $\pm\Omega_1 i, \pm\Omega_2 i$ of matrix S. If,

$$\Omega = \begin{pmatrix} 0 & -\Omega_1 & 0 & 0 \\ \Omega_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\Omega_2 \\ 0 & 0 & \Omega_2 & 0 \end{pmatrix} \quad (3)$$

Where, $\pm\omega_1 i, \pm\omega_2 i$, are the eigenvalues of matrix Ω, then,

$$V^{-1}SV = \begin{pmatrix} \Omega_1 i & 0 & 0 & 0 \\ 0 & -\Omega_1 i & 0 & 0 \\ 0 & 0 & \Omega_2 i & 0 \\ 0 & 0 & 0 & -\Omega_2 i \end{pmatrix} \quad (4)$$

Where, V, matrix forms from eigenvectors to eigenvalues $\pm\Omega_1 i, \pm\Omega_2 i$ for matrix Ω. Then, connect Eq. (1) with Eq. (3), then,

$$(UV^{-1})^{-1}SUV^{-1} = \Omega \quad (5)$$

If,

$$P = UV^{-1} \quad (6)$$

Then,

$$P^{-1}SP = \begin{pmatrix} 0 & -\Omega_1 & 0 & 0 \\ \Omega_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\Omega_2 \\ 0 & 0 & \Omega_2 & 0 \end{pmatrix} = \Omega \quad (7)$$

Where, P, transformation matrix. Assume,

$$X = PZ, Z = [z_1 \quad z_2 \quad z_3 \quad z_4]^T \quad (8)$$

Though the nonlinear portion influences are not taken into consideration for system stability through the state of zero balance (excluding critical attitudes), then,

$$P\dot{Z} = SPZ + \mu P^{-1}[\omega\sin(\omega\tau)B_1 - \cos(\omega\tau)B_2 - \bar{\alpha}B_3]PZ \quad (9)$$

Both sides multiplying of Eq. (9) with matrix inverse P,

$$\dot{Z} = SPZ + \mu[\omega\sin(\omega\tau)B_1 - \cos(\omega\tau)B_2 - \bar{\alpha}B_3]PZ \quad (10)$$

Make the relays,

$P^{-1}B_iP = A_i \quad , \qquad i = 1,2,3$ (11)

Enter Eq. (7) and Eq. (11) into Eq. (10),

$\dot{Z} = \Omega Z + \mu[\omega \sin(\omega\tau)A_1 - \cos(\omega\tau)A_2 - \overline{\alpha}A_3]Z$ (12)

Eq. (12) is changed into Eq. (13), introducing variable $t = \omega\tau$ and transforming time variable (τ),

$\frac{dZ}{dt} = \frac{\Omega}{\omega}Z + \mu\left[A_1 \sin(t) - \frac{1}{\omega}\cos(t)A_2 - \frac{\overline{\alpha}}{\omega}A_3\right]Z$ (13)

The vibration characteristics for non-conservative and conservative fluid conveying pipes will be investigated. Estimates of the natural frequencies for pipes is the essential purpose of this analysis. For that, there is a needed to gain the linear equations of motion in the district for the position of equilibrium. When the pulsating flow and external force are neglected and the pipe is in the steady state, the linearized equation of equation will be,

$\ddot{\eta} + 2M_r u_0 \dot{\eta}' + [u_0^2 + \Pi]\eta'' + \eta^{(4)} = 0$ (14)

The Eq. (14) is inhomogeneous where the derivative coefficients of η are frank functions of τ and ξ then the discretized equation of motion above, by using the Galerkin's way let,

$\eta(\xi, \tau) = \sum_{i=1}^{\infty} \phi_i(\xi)\, q_i(\tau)$ (15)

Where, $\phi_i(\xi)$ is an comparison function, $q_i(\tau)$ is an generalized coordinate where they satisfy all the boundary conditions. Choose the first three orders to manage researches, that is,

$\eta(\xi, \tau) = \sum_{i=1}^{3} \phi_i(\xi)\, q_i(\tau) = \phi_1(\xi)q_1(\tau) + \phi_2(\xi)q_3(\tau) + \phi_3(\xi)q_3(\tau)$ (16)

For pipes pinned at both ends, the function of its vibration model is,

$\phi_i = \sqrt{2}\sin(\lambda_i\xi), \qquad i = 1,2,3$ (17)

Where, λ_1, λ_2 and λ_3 are pipe eigenvalues. For,

$\lambda_1 = \pi$, $\lambda_2 = 2\pi$, $\lambda_3 = 3\pi$.

For pipes fixed at both ends, the function of its vibration model is,

$\phi_i = \cosh(\lambda_i\xi) - \cos(\lambda_i\xi) + \frac{\cosh(\lambda_i) - \cos(\lambda_i)}{\sinh(\lambda_i) - \sin(\lambda_i)}[\sin(\lambda_i\xi) - \sinh(\lambda_i\xi)], \quad i = 1,2,3$ (18)

Where,

$\lambda_1 = 4.73$, $\lambda_2 = 7.8532$, $\lambda_3 = 10.9956$.

For pipes pinned at one end and fixed at another end, the function of its vibration model is,

$\phi_i = \cos(\lambda_i\xi) - \cosh(\lambda_i\xi) + \frac{\cos(\lambda_i) - \cosh(\lambda_i)}{\sin(\lambda_i) - \sinh(\lambda_i)}[\sin(\lambda_i\xi) - \sinh(\lambda_i\xi)], \quad i = 1,2,3$ (19)

Note that,

$\lambda_1 = 3.9267$, $\lambda_2 = 7.0686$, $\lambda_3 = 10.2102$.

For pipes (cantilever), the function of its vibration model is,

$\phi_i = \cosh(\lambda_i\xi) - \cos(\lambda_i\xi) + \frac{\sinh(\lambda_i) - \sin(\lambda_i)}{\cosh(\lambda_i) + \cos(\lambda_i)}[\sin(\lambda_i\xi) - \sinh(\lambda_i\xi)], \quad i = 1,2,3$ (20)

Note that,

$\lambda_1 = 1.87512$, $\lambda_2 = 4.6941$, $\lambda_3 = 7.85476$.

Therefore, Eq. (15) is converted into matrix type, assuming,

$$\Phi = \begin{Bmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{Bmatrix},$$

And,

$$Q = \begin{Bmatrix} q_1 \\ q_2 \\ q_3 \end{Bmatrix}$$

Then,

$\eta(\xi, \tau) = \Phi^T Q = Q^T \Phi$ (21)

By compensation of Eq. (21) into Eq. (14), and assuming $H = u_0^2 + \Pi$, then,

$\phi^T\ddot{Q} + 2M_r u_0 \phi'^T\dot{Q} + H\phi''^T Q + \phi^{(4)T}Q = 0$ (22)

By multiplying Φ with two sides of Eq. (22) and then,

$\phi\,\phi^T\ddot{Q} + 2M_r u_0 \phi\,\phi'^T\dot{Q} + H\phi\,\phi''^T Q + \phi\,\phi^{(4)T}Q = 0$ (23)

The procedure ξ integral to Eq. (23) within interval [0,1], then the representation according to orthogonality, [18-20], for the function of trigonometric,

$$\int_0^1 \phi\,\phi^{T} d\xi = I = \begin{pmatrix} \int_0^1 \phi_1\phi_1^T & \int_0^1 \phi_2\phi_1^T & \int_0^1 \phi_3\phi_1^T \\ \int_0^1 \phi_1\phi_2^T & \int_0^1 \phi_2\phi_2^T & \int_0^1 \phi_3\phi_2^T \\ \int_0^1 \phi_1\phi_3^T & \int_0^1 \phi_2\phi_3^T & \int_0^1 \phi_3\phi_3^T \end{pmatrix} d\xi = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$$

$$\int_0^1 \phi\,\phi'^{T} d\xi = B = \begin{pmatrix} \int_0^1 \phi_1\phi_1'^T & \int_0^1 \phi_2\phi_1'^T & \int_0^1 \phi_3\phi_1'^T \\ \int_0^1 \phi_1\phi_2'^T & \int_0^1 \phi_2\phi_2'^T & \int_0^1 \phi_3\phi_2'^T \\ \int_0^1 \phi_1\phi_3'^T & \int_0^1 \phi_2\phi_3'^T & \int_0^1 \phi_3\phi_3'^T \end{pmatrix} d\xi = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix}$$

$$\int_0^1 \phi\,\phi''^{T} d\xi = C = \begin{pmatrix} \int_0^1 \phi_1\phi_1''^T & \int_0^1 \phi_2\phi_1''^T & \int_0^1 \phi_3\phi_1''^T \\ \int_0^1 \phi_1\phi_2''^T & \int_0^1 \phi_2\phi_2''^T & \int_0^1 \phi_3\phi_2''^T \\ \int_0^1 \phi_1\phi_3''^T & \int_0^1 \phi_2\phi_3''^T & \int_0^1 \phi_3\phi_3''^T \end{pmatrix} d\xi = \begin{pmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{pmatrix}$$

$$\int_0^1 \phi\,\phi^{(4)T} d\xi = \Lambda = \begin{pmatrix} \int_0^1 \phi_1\phi_1^{(4)T} & \int_0^1 \phi_2\phi_1^{(4)T} & \int_0^1 \phi_3\phi_1^{(4)T} \\ \int_0^1 \phi_1\phi_2^{(4)T} & \int_0^1 \phi_2\phi_2^{(4)T} & \int_0^1 \phi_3\phi_2^{(4)T} \\ \int_0^1 \phi_1\phi_3^{(4)T} & \int_0^1 \phi_2\phi_3^{(4)T} & \int_0^1 \phi_3\phi_3^{(4)T} \end{pmatrix} d\xi = \begin{pmatrix} \lambda_1^4 & & \\ & \lambda_2^4 & \\ & & \lambda_3^4 \end{pmatrix} \quad (24)$$

The specific boundary conditions are ϕ_1 , ϕ_2 and ϕ_3 which are the first three mode functions.

I. For pipes pinned at both ends, the B and C matrixes are,

$$B = \begin{pmatrix} 0 & -2.6667 & 0 \\ 2.6667 & 0 & -4.8 \\ 0 & 4.8 & 0 \end{pmatrix}$$

$$C = \begin{pmatrix} -(\pi^2) & 0 & 0 \\ 0 & -(2\pi^2) & 0 \\ 0 & 0 & -(3\pi^2) \end{pmatrix}$$

II. For fixed pipes at both ends, the matrix B and C are,

$$B = \begin{pmatrix} 0 & -3.3421 & 0 \\ 3.3421 & 0 & -5.5161 \\ 0 & 5.5161 & 0 \end{pmatrix}$$

$$C = \begin{pmatrix} -12.3028 & 0 & 9.7315 \\ 0 & -46.0501 & 0 \\ 9.7315 & 0 & -98.9047 \end{pmatrix}$$

III. For pipes pinned at one end and fixed at another end, the matrix B and C are,

$$B = \begin{pmatrix} 0 & -2.9965 & 0.3167 \\ 2.9965 & 0 & -5.1468 \\ -0.3167 & 5.1468 & 0 \end{pmatrix}$$

$$C = \begin{pmatrix} -11.5126 & 4.2814 & 3.7993 \\ 4.2814 & -42.8964 & 7.81913 \\ 3.7993 & 7.8191 & -94.0376 \end{pmatrix}$$

IV. For pipe (cantilever), the B and C matrixes are,

$$B = \begin{pmatrix} 2 & -4.75948 & 3.78433 \\ 0.75948 & 2 & -6.22218 \\ 0.21566 & 2.22218 & 2 \end{pmatrix}$$

$$C = \begin{pmatrix} 0.8581 & -11.7433 & 27.4531 \\ 1.8738 & -13.2942 & -9.04205 \\ 1.56453 & 3.22935 & -45.9043 \end{pmatrix}$$

Using Eq. (24), after the reduced order through Eq. (23), the discretized equation is shown below,

$$I\ddot{Q} + 2M_r u_0 B\dot{Q} + (CH + \Lambda)Q = 0 \tag{25}$$

Where,

$$\ddot{Q} = \begin{Bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \\ \ddot{q}_3 \end{Bmatrix},$$

$$\dot{Q} = \begin{Bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{Bmatrix},$$

$$Q = \begin{Bmatrix} q_1 \\ q_2 \\ q_3 \end{Bmatrix}$$

When,

$\dot{Q} = \Omega i$, $\ddot{Q} = -\Omega^2$,

And, Eq. (25) become,

$$[-I\Omega^2 + 2M_r u_0 B\Omega i + (CH + \Lambda)]Q = 0 \tag{26}$$

Or,

$$[-I\Omega^2 + 2M_r u_0 B\Omega i + (CH + \Lambda)] = S = \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{pmatrix} \tag{27}$$

Where,

$s_{11} = \lambda_1^4 + Hc_{11} + 2M_r u_0 b_{11}\Omega i - \Omega^2$
$s_{12} = Hc_{12} + 2M_r u_0 b_{12}\Omega i$
$s_{13} = Hc_{13} + 2M_r u_0 b_{13}\Omega i$
$s_{21} = Hc_{21} + 2M_r u_0 b_{21}\Omega i$
$s_{22} = \lambda_2^4 + Hc_{22} + 2M_r u_0 b_{22}\Omega i - \Omega^2$
$s_{23} = Hc_{23} + 2M_r u_0 b_{23}\Omega i$
$s_{31} = Hc_{31} + 2M_r u_0 b_{31}\Omega i$
$s_{32} = Hc_{32} + 2M_r u_0 b_{32}\Omega i$
$s_{33} = \lambda_3^4 + Hc_{33} + 2M_r u_0 b_{33}\Omega i - \Omega^2$

By setting $|S|$ equal to zero, it is possible to evaluate the natural frequency (Ω). The following characteristic equation comes from the expansion of determent above,

$$\Omega^6 - k_5\Omega^5 i - k_4\Omega^4 - k_3\Omega^3 i - k_2\Omega^2 - k_1\Omega i - k_0 = 0 \tag{28}$$

The constants k_0 , k_1 , k_2 , k_3 , k_4 , k_5 depend on the boundary conditions, and shown in Table 1. For Root-Locus analysis, the closed-loop transfer function for any feedback control system may be written in the factored form given in equation,

$$\frac{C}{R}(s) = \frac{G(s)}{1+G(s)H(s)} = \frac{K_c(s-z_{c1})(s-z_{c2})\ldots(s-z_{cn})}{(s-p_{c1})(s-p_{c2})\ldots(s-p_{cn})} \tag{29}$$

Where, $s = p_{c1}, p_{c2}, \ldots p_{cn}$ are closed-loop poles, so called since their values make Eq. (29) infinite (Note that they are also the roots of the characteristic equation) and $s = z_{c1}, z_{c2}, \ldots z_{cn}$ are closed-loop zeros, since their values make Eq. (29) zero. The position of the closed-loop poles in the s-plane determine the nature of the transient behaviour of the system as can be seen in Fig. 1. Also, the open-loop transfer function may be expressed as,

$$G(s)H(s) = \frac{K(s-z_{01})(s-z_{02})\ldots(s-z_{0n})}{(s-p_{01})(s-p_{02})\ldots(s-p_{0n})} \tag{30}$$

Where $z_{01}, z_{02}, \dots z_{0n}$ are open-loop zeros and $p_{01}, p_{02}, \dots p_{0n}$ are open-loop poles.
This is a control system design technique developed by W.R. Evans (1948) that determines the roots of the characteristic equation (closed-loop poles) when the open-loop gain-constant K is increased from zero to infinity. The locus of the roots, or closed-loop poles are plotted in the s-plane. This is a complex plane, since $s = \sigma \pm j\omega$ It is important to remember that the real part σ is the index in the exponential term of the time response, and if positive will make the system unstable. Hence, any locus in the right-hand side of the plane represents an unstable system.
The imaginary part! is the frequency of transient oscillation. When a locus crosses the imaginary axis, $\sigma = 0$. This is the condition of marginal stability, i.e. the control system is on the verge of instability, where transient oscillations neither increase, nor decay, but remain at a constant value. The design method requires the closed-loop poles to be plotted in the s-plane as K is varied from zero to infinity, and then a value of K selected to provide the necessary transient response as required by the performance specification. The loci always commence at open-loop poles (denoted by x) and terminate at open-loop zeros (denoted by o) when they exist. Eq. (28) and Eq. (30), By setting |S| equal to zero, it is possible to evaluate the natural frequency (Ω). Using Eq. (15), the characteristic equation for three modes. The constants k depend on the boundary conditions. Will be used to find the results of Root-Locus.
Therefore, the analytical solution results calculated can be depending to analysis the control and stability for dynamic behaviour of pipe conveying fluid, since the analytical technique was agreement solution can be applied for different engineering structure with various parameters effect, [21-23]. In addition, can be comparison the analytical results with other numerical, [24-26] or experimental, [27-30], results calculated or also can be comparison the analytical results with previous results calculated by others researches, [31-34], to given the agreement for presenting technique used.

Table 1. Parameter Constants for Pipe with Various Boundary Conditions Supported.

Parameter Constants	Pipe Supported	
	Pinned-Pinned	Clamped-Clamped
k_0	$\left(\begin{matrix}-34609.9\,H^3 + 0.478222*10^7\,H^2 - \\ 0.165195*10^9\,H + 0.119786*10^{10}\end{matrix}\right)$	$\left(\begin{matrix}-51673H^3 + 0.148296*10^8\,H^2 - \\ 0.120933*10^{10}\,H + 0.278330*10^{11}\end{matrix}\right)$
k_1	0	0
k_2	$\left(\begin{matrix}+3436.55M_r^2u_0^2H - 233439M_r^2u_0^2 - \\ 4773.04H^2 + 555683H - \\ 0.132176*10^8\end{matrix}\right)$	$\left(\begin{matrix}+4481.05M_r^2u_0^2H - 714029M_r^2u_0^2 - \\ 6243.22H^2 + 0.134854*10^7H - \\ 0.648214*10^8\end{matrix}\right)$
k_3	0	0
k_4	$(-138.175H + 9546.1 + 120.608M_r^2u_0^2)$	$(-157.258H + 18922 + 166.388M_r^2u_0^2)$
k_5	0	0
	Pipe Supported	
	Clamped-Pinned	Cantilever
k_0	$\left(\begin{matrix}-43139.2H^3 + 0.877896*10^7\,H^2 - \\ 0.478995*10^9\,H + 0.645029*10^{10}\end{matrix}\right)$	$\left(\begin{matrix}+441.872H^3 + 8265.4\,H^2 + \\ 684784\,H + 0.228488*10^8\end{matrix}\right)$
k_1	$(-0.0613238TM_ru_0 + 0.005T^2M_ru_0)$	$\left(\begin{matrix}-154473TM_ru_0 + 1835.27T^2M_ru_0 + \\ (7604890*10^7M_ru_0)\end{matrix}\right)$
k_2	$\left(\begin{matrix}+4030.57M_r^2u_0^2H - 416514M_r^2u_0^2 - \\ 5516.43H^2 + 887358H - 0.303083*10^8\end{matrix}\right)$	$\left(\begin{matrix}+565.864M_r^2u_0^2H - 123009M_r^2u_0^2 - \\ 567.72H^2 + 69941.7H \\ -0.190122*10^7\end{matrix}\right)$
k_3	$(+0.003TM_ru_0 - 0.001M_r^3u_0^3)$	$\left(\begin{matrix}+374.357TM_ru_0 - 432.196M_r^3u_0^3 \\ -34435.5M_ru_0\end{matrix}\right)$
k_4	$(-148.447H + 13601.8 + 142.275M_r^2u_0^2)$	$\left(\begin{matrix}-58.3405H + 4304.44 \\ +114.502M_r^2u_0^2\end{matrix}\right)$
k_5	0	$(+12M_ru_0)$

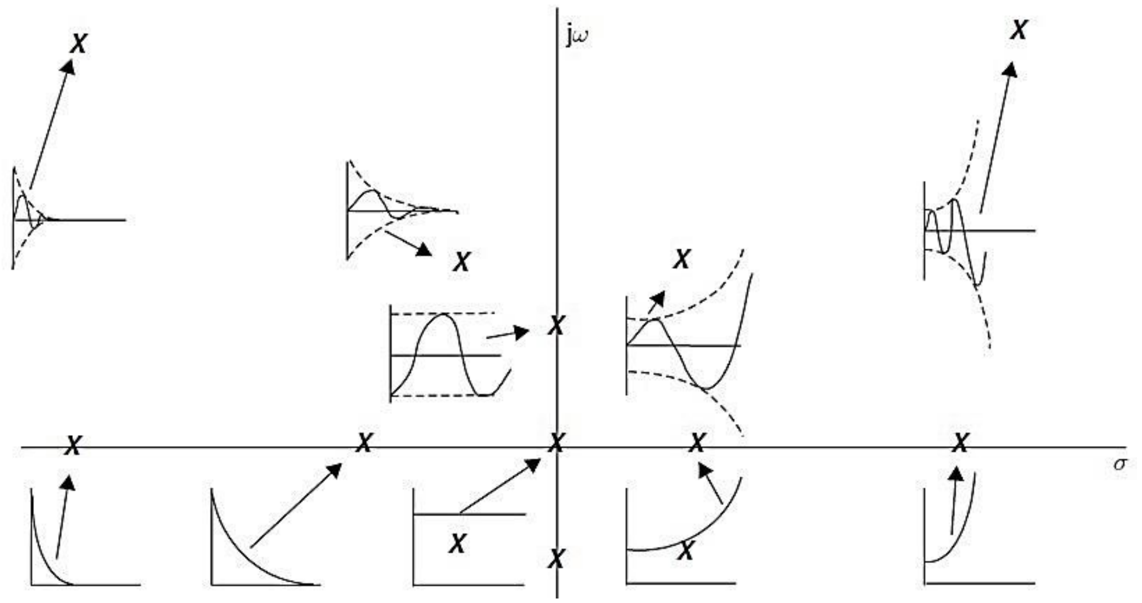


Figure 1. Effect of closed-loop pole position in the s-plane on system transient response.

3. Results and Discussion

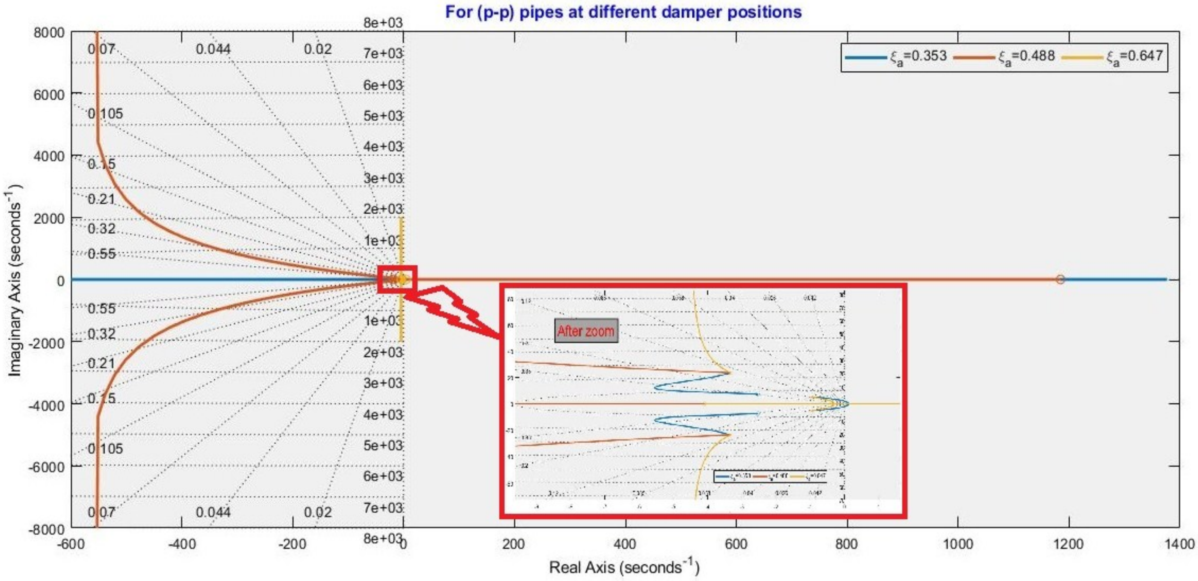
The Root Locus Theory draws a map to determine the location and paths of the roots of the characteristic equation. The root position is very useful in studying the active control system and the MATLAB 2018 software will be used to map the root position. As a design engineer, it is important to know the root location for the purposes of designing an active control system that is successful. The root position can also be used to study the behavior of the roots of any algebraic equation with one or several parameters. All cases of pipe fixation which are (p-p), (c-p), (c-c) and cantilever pipe will be dealt with,

I. Effect of the Hydraulic Damper Position

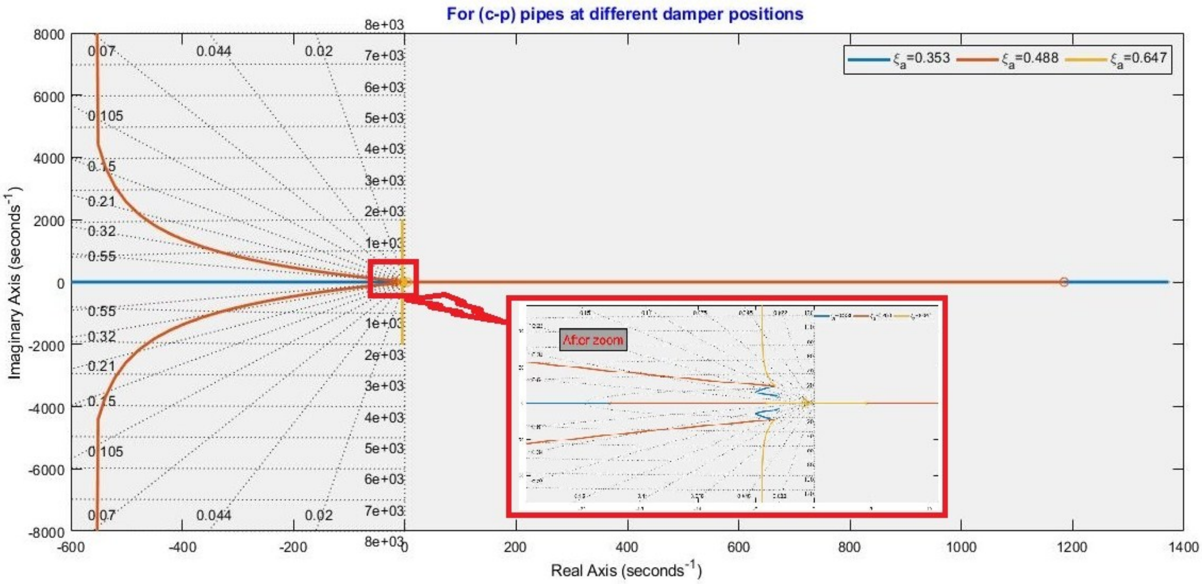
Fig. 2, shows the locations, paths of the roots, the change in gain at each case, the stability, the overshoot, the location of the poles, the location of the zeros, the frequency of transient oscillation and the behavior of the system in general. This is done for various damper locations, with $u_o = 1$, $\alpha = 0.01$, and base width of hydraulic damper ($\Delta\xi = 0.1$). For pin fixation on both sides, it is observed that the highest stability occurs at $\xi_a = 0.353$ with low frequency oscillation capacity. It is followed by stability at $\xi_a = 0.488$ and the lowest marginal stability is achieved at $\xi_a = 0.647$. Note that the location of the damper occurs at $\xi_a = 0.488$ in which the highest amplitude of the frequency of transient oscillation occurs. The results are almost identical to the fixation (c-p) pipe for the length of the large pipe in the subject of study, except for the approaching roots to the left in the chart, which means that the increased stability will be higher. As for the case of fixation (c-c) pipe, there is an approach to the roots to the left more than the previous two cases. This means an increased stability in this case, with an approximation in the frequency amplitude of the transition oscillation. The fixation cantilever pipe has the highest stability at $\xi_a = 0.488$ with high amplitude of the frequency of transient oscillation. The lowest stability occurs at $\xi_a = 0.647$ with average oscillation capacity compared to other locations, but the system in this case is about to collapse and fail. This is due to the position of the nearby roots on the right side of the chart.

II. Effect of the Base Width of Hydraulic Damper

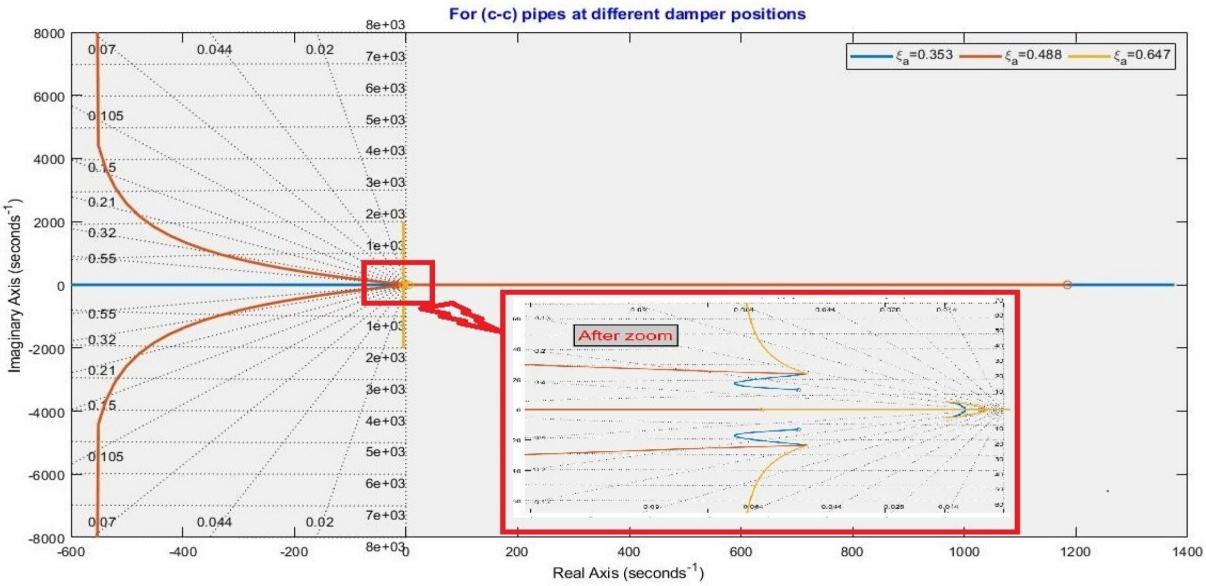
Fig. 3, shows the locations, paths of the roots, the change in gain at each case, the stability, the overshoot, the location of the poles, the location of the zeros, and the behavior of the system in general. This is done with the same survival locations previously selected for the damper, with $u_o = 1$, $\alpha = 0.01$, and damper location $\xi_a = 0.5$. In the case of (p-p) pipe, the highest stability occurs at $\Delta\xi = 0.05$ and the amplitude of the transition oscillation frequency is low at low frequencies and the amplitude rises at high frequencies. The overshoot rises as the frequency at $\Delta\xi = 0.05$ the gain also rises with higher frequency and the marginal stability at $\Delta\xi = 0.2$. The case (c-p) pipe has the highest stability at $\Delta\xi = 0.05$ and is accompanied by the highest frequency amplitude. The case of (c-c) pipe is the highest stable at $\Delta\xi = 0.2$ accompanied by a high amplitude with an oscillation frequency of transition. More stability than the previous two cases is noted and the roots of all $\Delta\xi$ approaches are to the left of the diagram. The case of cantilever pipe is somewhat close to all $\Delta\xi$ cases, with a high transitional amplitude.



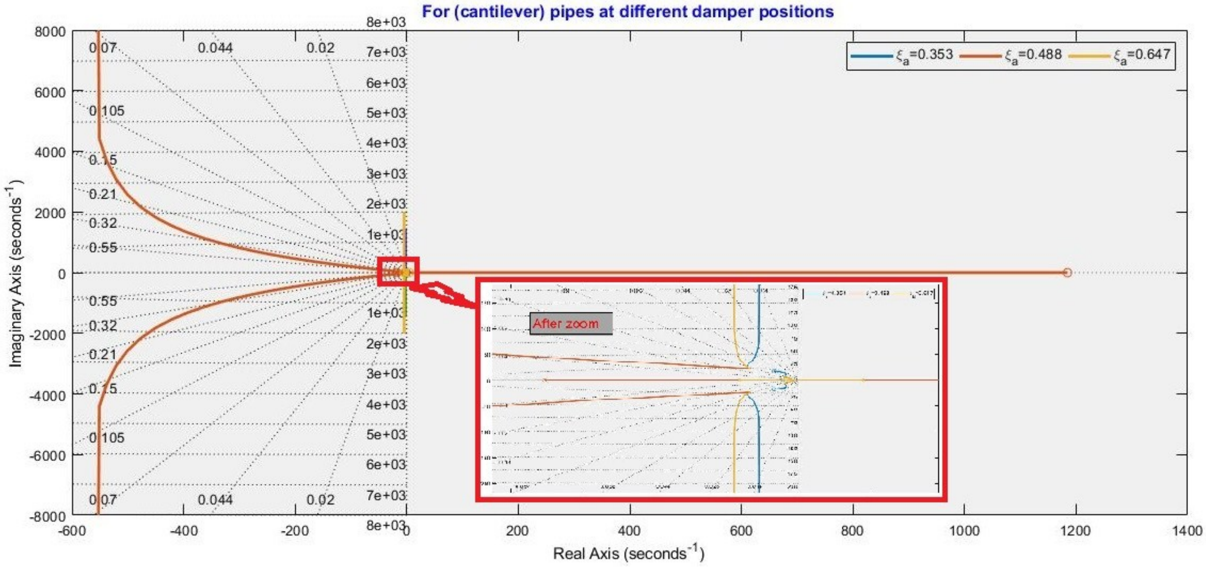
a. P-P Pipe Supported.



b. C-P Pipe Supported.

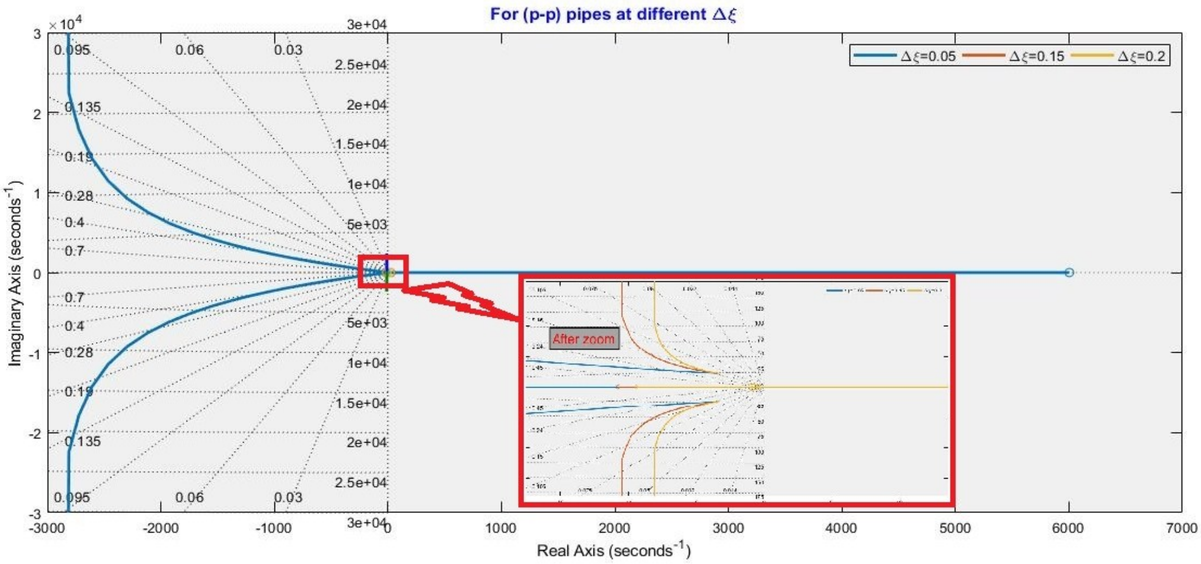


c. C-C Pipe Supported

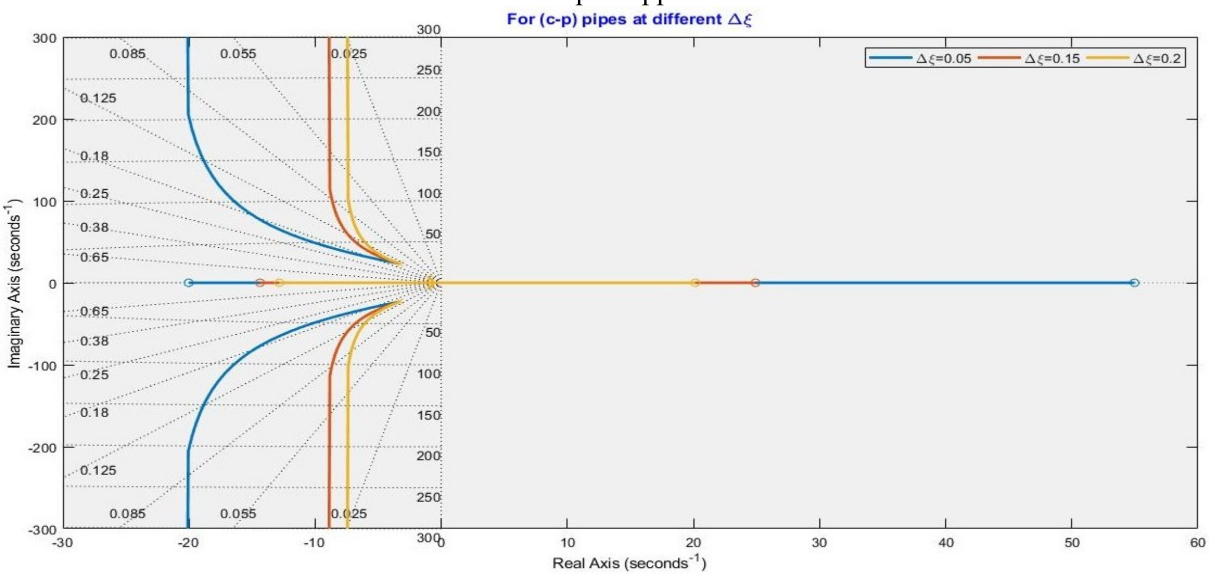


d. Cantilever Pipe Supported

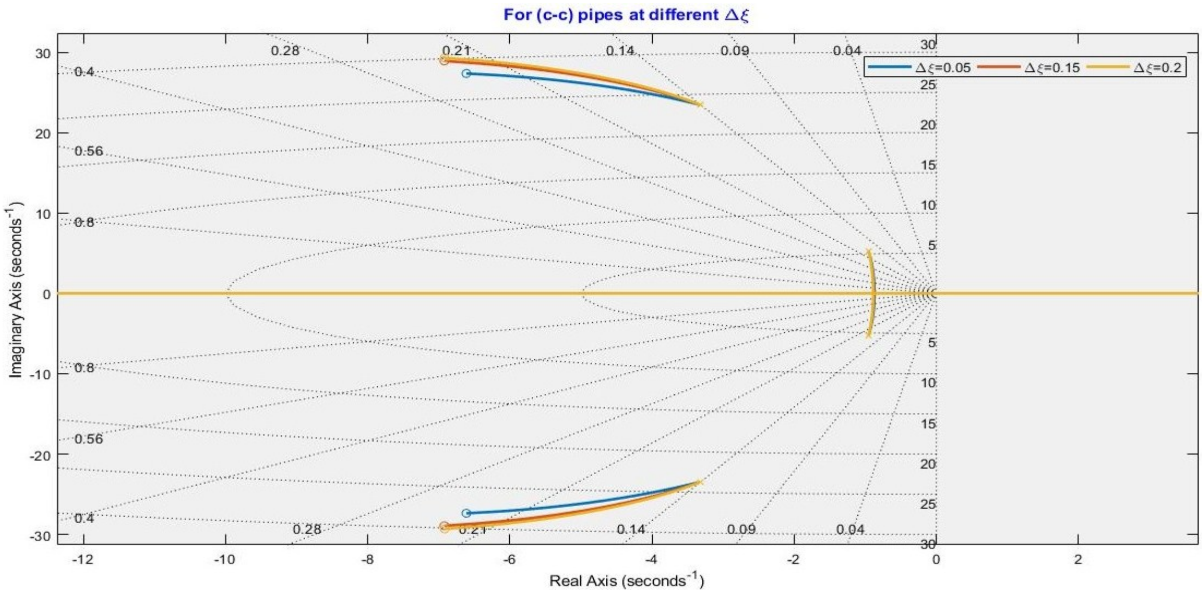
Figure 2. Root Locus at different damper positions.



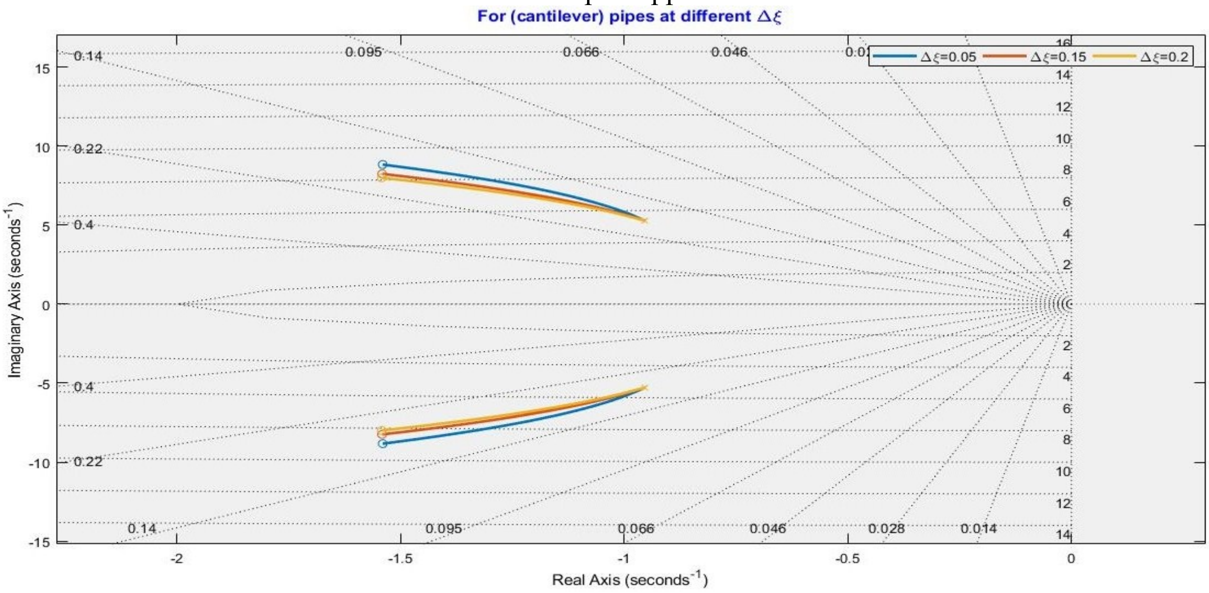
a. P-P Pipe Supported.



b. C-P Pipe Supported.



c. C-C Pipe Supported



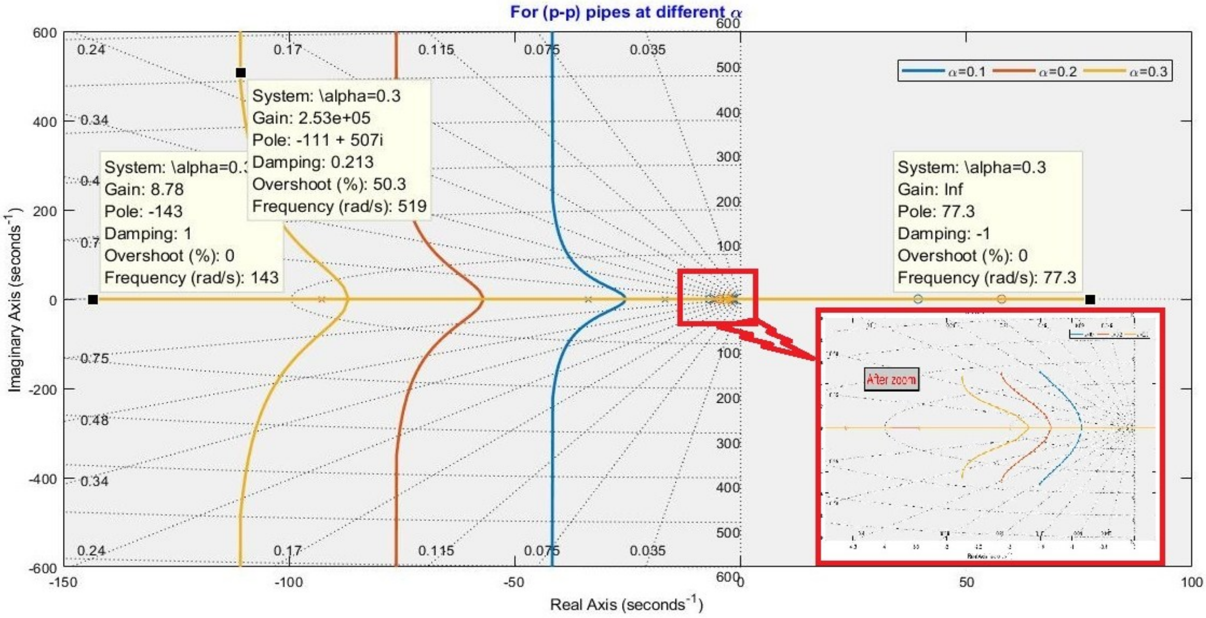
d. Cantilever Pipe Supported

Figure 3. Root Locus at different $\Delta\xi$.

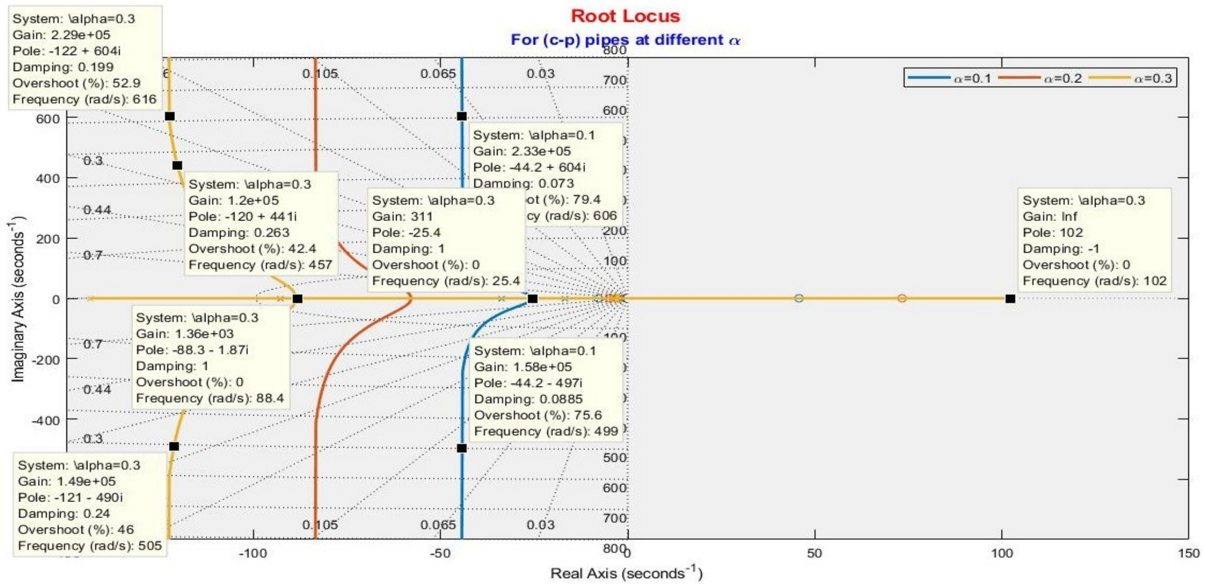
III. Effect of the Damping

Fig. 4, shows the locations, paths of the roots, the change in gain at each case, the stability, the overshoot, the location of the poles, the location of the zeros, and the behavior of the system in general, with $u_o = 1$, $\xi_a = 0.5$, and base width of hydraulic damper ($\Delta\xi = 0.15$).

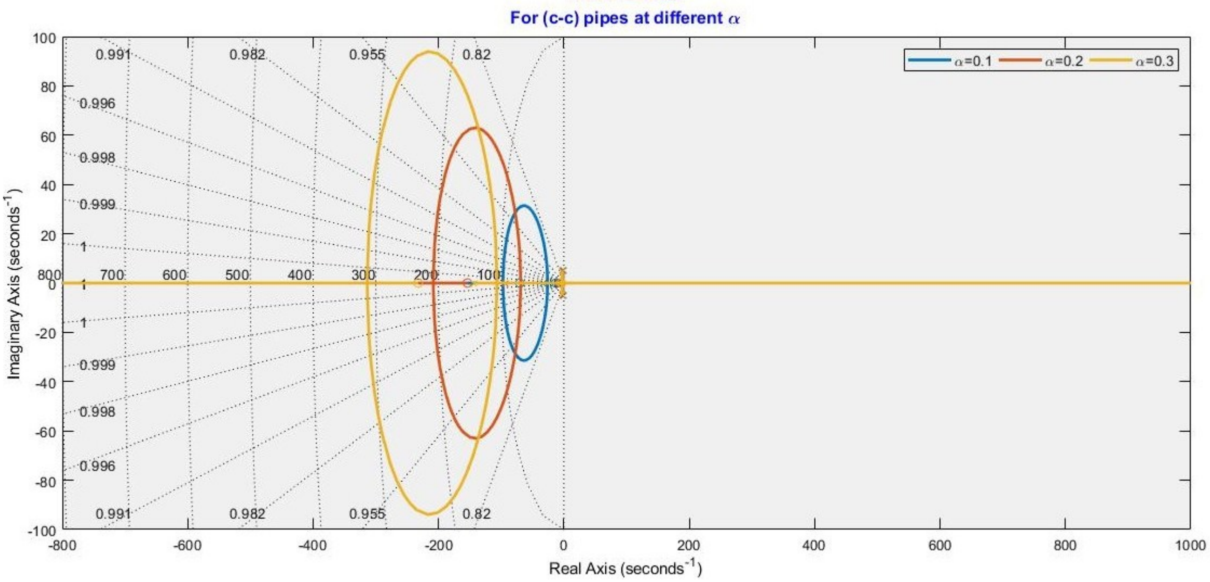
For pin fixation on both sides, it is observed that the highest stability occurs at $\alpha = 0.3$ with low frequency oscillation capacity. It is followed by stability at $\alpha = 0.2$ and the lowest marginal stability is achieved at $\alpha = 0.1$. Note that the location of the damper occurs at $\alpha = 0.3$ in which the highest amplitude of the frequency of transient oscillation occurs. The case of (c-p) pipe has the highest stability at $\alpha = 0.3$ and is accompanied by the highest frequency amplitude. As for the case of fixation (c-c) pipe, closed circular loops are created representing analogue stability. With respect to frequencies, there is an approach to the roots to the left more than the previous two cases. This means an increased stability in this case, with an approximation in the frequency amplitude of the transition oscillation. The fixation cantilever pipe has the highest stability at $\alpha = 0.3$ with high amplitude of the frequency of transient oscillation. The lowest stability occurs at $\alpha = 0.1$ with high oscillation capacity compared to other (α) and compared to other fixation cases.



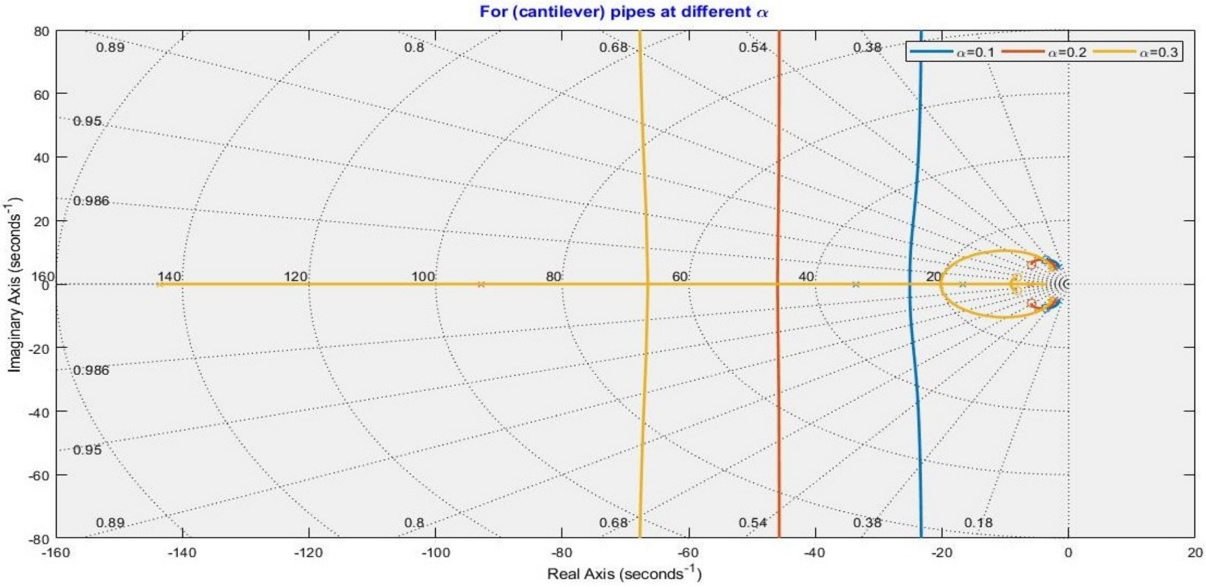
a. P-P Pipe Supported.



b. C-P Pipe Supported.



c. C-C Pipe Supported



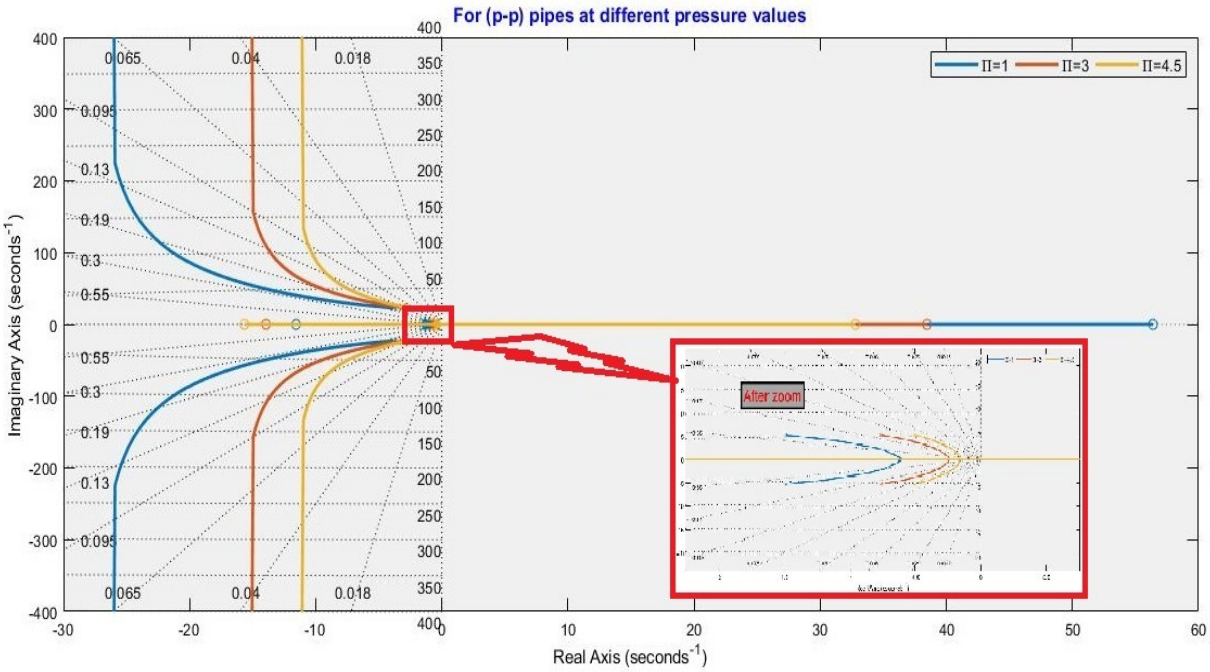
d. Cantilever Pipe Supported

Figure 4. Root Locus at different α.

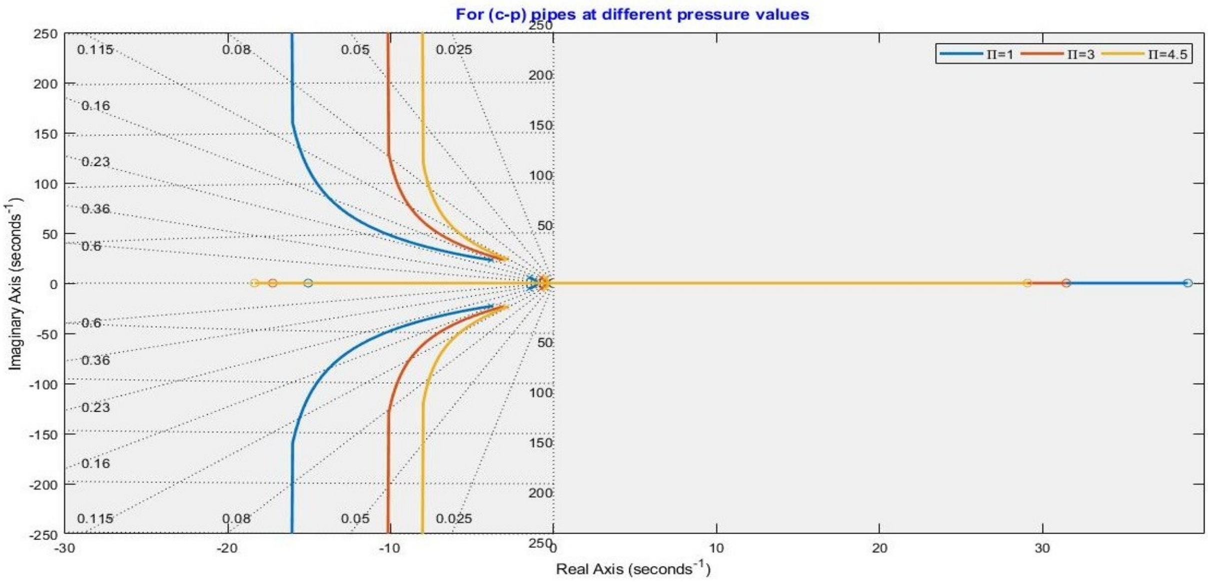
IV. Effect of Pressure

Fig. 5, shows the locations, paths of the roots, the change in gain at each case, the stability, the overshoot, the location of the poles, the location of the zeros, and the behavior of the system in general, with $\alpha = 0.01$, and base width of hydraulic damper ($\Delta\xi = 0.1$), $\xi_a = 0.5$.

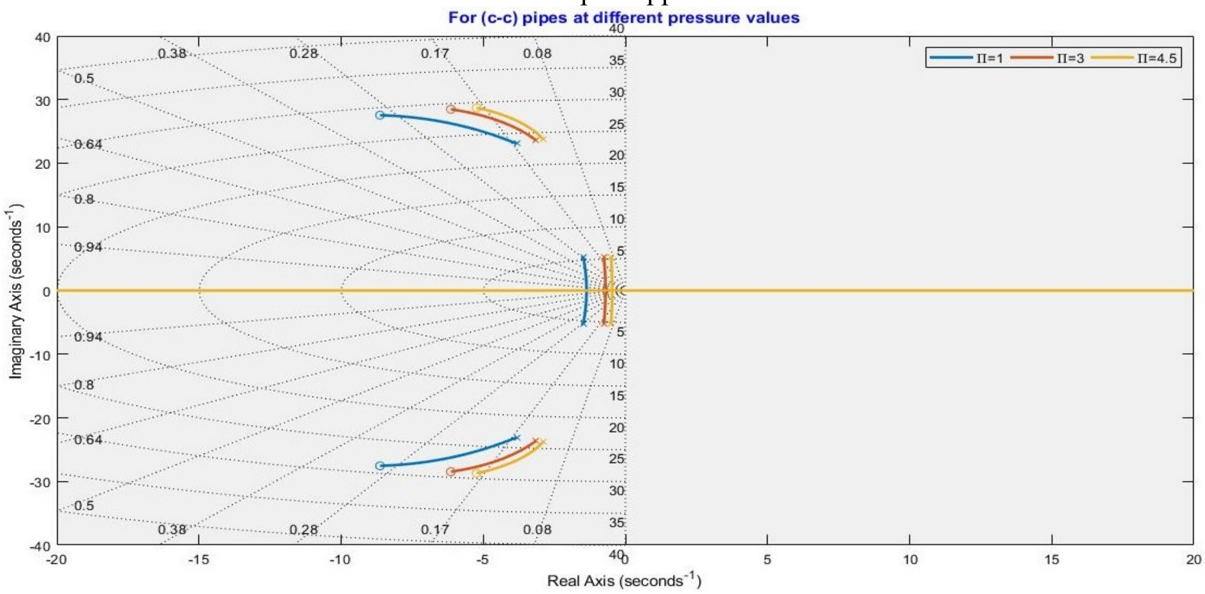
In the case of (p-p) pipe, the highest stability occurs at $\Pi = 1$ and the amplitude of the transition oscillation frequency is low at low frequencies and the amplitude rises at high frequencies. The overshoot rises as the frequency at $\Pi = 1$. The gain also rises with higher frequency and the marginal stability at $\Pi = 4.5$. The case of (c-p) pipe has the highest stability at $\Pi = 1$ and is accompanied by the highest frequency amplitude. The case of (c-c) pipe is the highest stable at $\Pi = 1$, accompanied by a high amplitude with a oscillation frequency of transition. More stability than the previous two cases is noted and the roots of all Π approaches are to the left of the diagram. The cantilever pipe becomes close to instability at a pressure of 4.5.



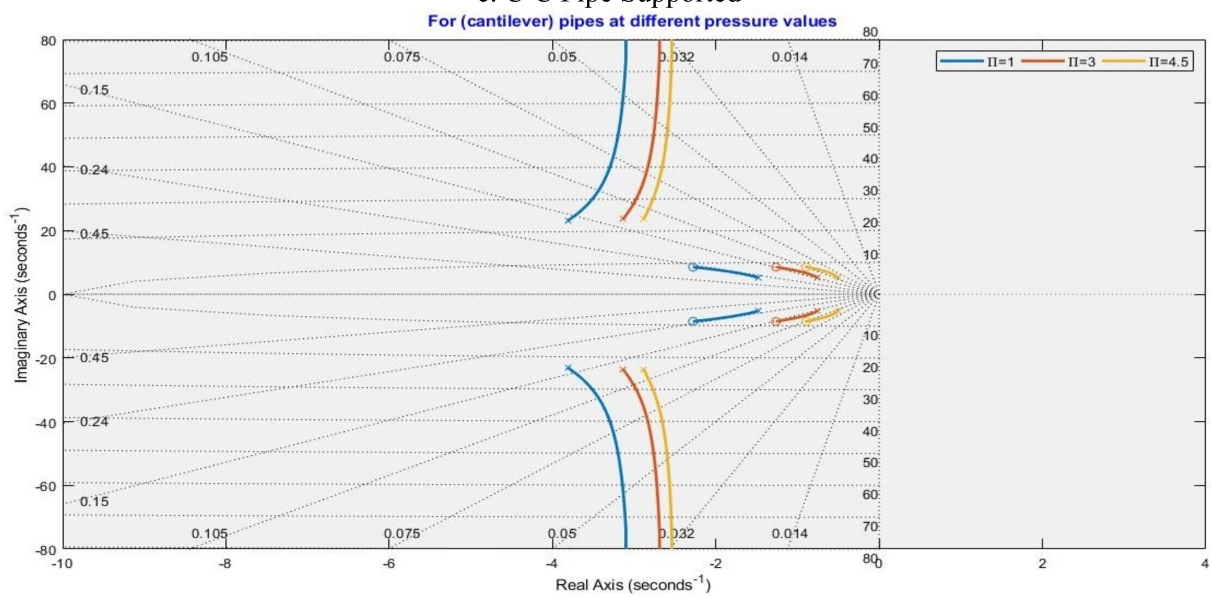
a. P-P Pipe Supported.



b. C-P Pipe Supported.



c. C-C Pipe Supported



d. Cantilever Pipe Supported

Figure 5. Root Locus at different Π.

4. Conclusion

From the analytical solution for general equation of motion for pipe conveying fluid, to determine the dynamic stability of pipe by using root locus technique, can be listing the following impartment points,

1. The results of the change of the parameters of each fixations, were compared with each control theory used and found a match in stability and response.
2. In all types of pipes, increased speed leads to a decrease in natural frequencies and increase pressure. When the speed is increased, the control performance decreases due to the increased force of Coriolis.
3. For critical speeds, the increase in pressure reduces those speeds for all types of fixings for pipes. Then, increase in pressure leads to the failure of pipe systems at certain limits if the results are not calculated with high accuracy.
4. Increase the proportion of mass less critical speeds and all types of fixations for pipes.
5. The increase in pressure for critical speeds, reduces those speeds for all types of fixings for pipes, increase the proportion of mass less critical speeds and all types of fixations for pipes.

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