INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 11, Issue 1, 2020 pp.29-46
Journal homepage: www.IJEE.IEEFoundation.org

Experimental investigation of an active control system for vibration a pipe conveying fluid

Dhurgham Salah Hussein, Muhannad Al-Waily

Department of Mechanical Engineering, Faculty of Engineering, University of Kufa, Iraq.

Received 05 Nov. 2019; Received in revised form 25 Feb. 2020; Accepted 05 Mar. 2020; Available online 1 June 2020

Abstract
Vibration control is achieved by increasing the pressure of the hydraulic damper through a differential pressure gauge that connects to the main pipe, which in turn relates to the electric control valve where the amount of pressure coming out of this valve can be controlled by differential pressure gauge. Thus the hydraulic damper pressure and vibration inside the pipe are controlled. This was done in an actual water pumping station. The operational conditions of that station are taken into account in terms of the pressure generated and the flow rate at different times from the peak demand to the lowest consumption. A damping system is manufactured and connected to reduce vibrations. The normal frequency is measured for several types of fixations, and for the different circumstances in the experimental way. The results are compared with the results calculated by the theoretical method where it is found that the rate of convergence of results is very good and the rate is not exceeding 11.539%. In conclusion, the results have shown that the addition of the hydraulic damper increases the amount of natural frequency of the pipes and thus reduces the amount of response, which leads to a marked increase in the stability of the pipes during the flow. In addition, it is possible to find the imaginary frequency that indicates the stability of the pipes. The results have shown that the imaginary frequency can be reduced (increase stability) by adding a vibration damper to the piping system.

Keywords: Active Vibration Control; Pipe Conveying Fluid; Data Acquisition Device; Accelerometer Sensor; Differential Pressure; Hydraulic Damper.

1. Introduction
Every year, huge economic losses occur in advanced countries due to the vibration of pipes. The annual damage due to vibrations in pipelines in developed countries is estimated at 10 billion dollars, according to Canadian experts. Therefore, research on the study of vibrations in fluid pipe conveying fluid systems has an engineering and economic value [1]. Therefore, it is necessary to find control systems to reduce the vibrations generated in the pipes. Pipes conveying fluid are widely used in aircraft power plants, ships, nuclear industry, oil, and energy industry, metallurgy industry, power industry, biological engineering, marine engineering, and in everyday life. The main purpose of pipes is to transmit energy or energy flow, mass liquid flow. In all industries, pipes are used to transport fluids of all kinds. Despite this proliferation and extreme importance of the pipes, these pipes are used in the different fields of the system and the presence of vibrations, which leads to damage to the systems or damage to the pipes in addition to the

resulting noise. In general, the behavior of dynamic for fluid conveying pipes is more complex than the structure without fluid. When the tube is without fluid, the stiffness and mass are determined only by the free vibrations of the structure (boundary conditions and degree of freedom). In this structure, the Eigen values are attached to the parameters of the structure, subsequently, the natural frequency is singular. The control type is then uncontrolled for vibrations generated, [2]. There, the pipe conveying fluid vibration investigation by multi researchers with different parameters for pipe and fluid flow, then, the following researches given same for this investigation, as,

At, 1995, C. H. Yau et. al., [3], developed an active control vibration system, a controller of robust, such as a system with high flow velocity differences, without gain - scheduling or flow sensor, is developed. The method of robust control is based on a latterly progressed sensitivity–based on Quantitative Feedback Theory (QFT) planner, that allows the control unit to make a closed loop response to meet the quantitatively definite requirements of performance despite that the system has significant differences in the parameters. The QFT system results in a wonderful robustness stability in relation to changes in flow velocity. Numerical simulations are done for the various controllers and to perform the activity of the suggested control planner. Then, at 2003, Z. Jiao et. al., [4], the theory is explained in this study to test the active control of the vibration in the fluid supply system with detailed water supply. This method is adjusted and the robust control of various frequencies and disturbances of load are able to retain their vibrations at the lowest level down speeds of the variable pump. The technology of multi-layer piezoelectric (PZT) orifice valve is driven and is modeled with the feature of the proportional for an opening area of the generated control voltage, small size, and high bandwidth for frequency.

Then, at, 2014, Zhen Wang et. al., [5], used the active control to find the algorithm of adaptive analysis and frequency in the digital signal processing system. The researchers conducted the experiment on the closed-pipe pump, where the acceleration was recorded with control and without control when the system of the pump and pipes was at different frequencies. It was also found that the inertial motor can suppress vibrations at the ends of the pipe and at the base point of the system. After this, at 2016, T. Zhang et al., [6], studied influence of the lumped masses and additional linear springs at positions arbitrary along the pipe are taken into account in the equations mentioned above. The linearized dynamic equations are used to find the natural frequencies of pipes with several various boundary conditions for the sake of verifying the validity of the method when comparing the results obtained with the results obtained by other sources. The nonlinear dynamic manner of the pipes with various boundary conditions by using the Runge-Kutta diagram, is used to anatomize by solving the nonlinear equations. It is found that the method offered in the research could effectively solve the problem of nonlinear vibration of fluid conveying pipes, with boundary conditions general and extra masses and springs.

At, 2017, X. Dekui et. al., [7], they designed a type of MR pipeline vibration, and discussed the strategy of the pipe clamp and the algorithm of semi-active control. They found during analysis and discussion that, the MR damper which works on principle intelligent material can be modified continuously, with real-time and good controllability. The algorithm of predictive intelligent feedback control, is a mechanism for semi-effective control in vibrations. It is a virtual scheme that has wide global applications in control of vibrations of hydraulic systems. Also, at same year, O. Kavianipour, [8], designed damper of electromagnetic consists of DC motor, a permanent-magnet, a nut , and a ball screw. The main aim of the present work is to reduce the pipe vibration eventual from the velocity of the fluid and allow it to transform to the energy of electric. To implement this goal, the vibration and stability of the beam sample were studied using Newmark and Ritz methods. It was noticed that increasing the velocity of fluid results in a decrease in the movement of the free end for the pipe . The simulation showed the results which the designed damper controlled of electromagnetic semi-active by the control strategy off-on damping where the vibration amplitude was lowered for the pipe around 5.9 %, energy of regenerated about 1.9 (MJ/sec). It showed also that the designed electromagnetic damper semi-active has a best energy regeneration and performance more than the electromagnetic damper passive. Also, at 2017, M. J. Jweeg et. al., [9], studied the dynamic behavior for vibration pipe with effect of different crack parameters. Where, the investigation included calculated the natural frequency for pipe conveying fluid experimentally and analytically techniques. Thus, the experimental work included build a vibration pipe rig to measurement the natural frequency of pipe, and, the analytical solution included drive the general equation for motion for pipe and then solution its equation for simply supported pipe. In addition, comparison the results obtained by experimental and analytical solution together. Also, at same year M. Al-Waily et. al., [10], investigation the effect of crack angle on the dynamic behavior for pipe by using experimental and numerical techniques. Thus, the numerical technique used finite element method to calculate the natural frequency for pipe with different crack angle effect. After this comparison the results calculated by experimental results obtained.

Finally, at 2019, D. S. Hussein et. al., [11], studied the active control for vibration pipe with various flow and damper parameters effect. Thus, the investigation included calculated the vibration response and control for pipe vibration by using analytical solution. Where, the analytical solution included drive the general equation of motion for vibration pipe conveying fluid, and then, solution its equation by using state space method to calculate the vibration response for pipe and the control of pipe with different parameters effect. In addition, at same researchers and year, [12], used bode diagram technique to calculated the stability for pipe with different damper and flow fluid parameters effect. Where, the investigation included used the analytical solution presented in [11] to drive the bode diagram for pipe.

There, in this study presenting design for active damper to control on the vibration response for pipe conveying fluid. Thus, the investigation including manufacturing active damper and supporting on the vibration pipe system, and then, variable the damper coefficient accordant on the vibration response, to control on the vibration response pipe with constant value at different flow parameters effect. In addition, calculating the natural frequency for pipe experimentally and then comparison the results with analytical natural frequency results, calculating by solution for the general equation of motion for vibration pipe, for different pipe boundary conditions and various damper and fluid flow parameters effect.

2. Analytical Investigation

A theoretical analysis of the dynamical behavior and vibration of fluid conveying pipes will be offered in this study. For clarity, at the beginning, studies dynamics, and stability of pipe conveying fluid and then studies the active vibration control of pipes fluid conveying. 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. Primarily, the motion differential equation of pipes is built, secondly, the differential equation of system state is gained through reduced order treatments, discretization and dimensionless. Then the average method in used to forerun average treatment on the differential equation of system state, based on the averaged independent equation, analyzing the stability of zero balance status. 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, [13-17]. 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 will be, [11-12],

$$\ddot{\eta} + 2M_r u_0 \dot{\eta}' + [u_0^2 + \Pi]\eta'' + \eta^{(4)} = 0 \tag{1}$$

The Eq. (1) 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,

$$\eta(\xi,\tau) = \sum_{i=1}^{\infty} \phi_i(\xi)\, q_i(\tau) \tag{2}$$

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,

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

where, ϕ_i are vibration model depending on the pipe supported, then,

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

$$\phi_i = \sqrt{2}\sin(\lambda_i\xi), \qquad i = 1,2,3 \tag{4}$$

Where, $\lambda_1 = \pi$, $\lambda_2 = 2\pi$, $\lambda_3 = 3\pi$, which, λ_1 , λ_2 and λ_3 are pipe eigenvalues.

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

$$\phi_i = \cosh(\lambda_i\xi) - \cos(\lambda_i\xi) + \frac{\cosh(\lambda_i)-\cos(\lambda_i)}{\sinh(\lambda_i)-\sin(\lambda_i)}[\sin(\lambda_i\xi) - \sinh(\lambda_i\xi)], \qquad i = 1,2,3 \tag{5}$$

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

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

$$\phi_i = \cos(\lambda_i\xi) - \cosh(\lambda_i\xi) + \frac{\cos(\lambda_i)-\cosh(\lambda_i)}{\sin(\lambda_i)-\sinh(\lambda_i)}[\sin(\lambda_i\xi) - \sinh(\lambda_i\xi)], \qquad i = 1,2,3 \tag{6}$$

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

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

$$\phi_i = \cosh(\lambda_i\xi) - \cos(\lambda_i\xi) + \frac{\sinh(\lambda_i)-\sin(\lambda_i)}{\cosh(\lambda_i)+\cos(\lambda_i)}[\sin(\lambda_i\xi) - \sinh(\lambda_i\xi)], \qquad i = 1,2,3 \tag{7}$$

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

Then, Eq. (2) is converted into matrix type, assuming,

$$\Phi=\begin{Bmatrix}\phi_1\\ \phi_2\\ \phi_3\end{Bmatrix},\ Q=\begin{Bmatrix}q_1\\ q_2\\ q_3\end{Bmatrix}$$

Then,

$$\eta(\xi,\tau)=\Phi^TQ=Q^T\Phi \tag{8}$$

By compensation of Eq. (8) into Eq. (1), and assuming, $H=u_0^2+\Pi$, then,

$$\phi^T\ddot{Q}+2M_ru_0\phi'^T\dot{Q}+H\phi''^TQ+\phi^{(4)T}Q=0 \tag{9}$$

By multiplying Φ with two sides of Eq. (9) and then,

$$\phi\,\phi^T\ddot{Q}+2M_ru_0\phi\,\phi'^T\dot{Q}+H\phi\,\phi''^TQ+\phi\,\phi^{(4)T}Q=0 \tag{10}$$

The procedure ξ integral to Eq. (10) within interval [0,1], then the representation according to orthogonality, [18-21], for the function of trigonometric,

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

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

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

$$\int_0^1\phi\,\phi^{(4)T}d\xi=\Lambda=\begin{pmatrix}\int_0^1\phi_1\phi_1^{(4)T} & \int_0^1\phi_2\phi_1^{(4)T} & \int_0^1\phi_3\phi_1^{(4)T}\\ \int_0^1\phi_1\phi_2^{(4)T} & \int_0^1\phi_2\phi_2^{(4)T} & \int_0^1\phi_3\phi_2^{(4)T}\\ \int_0^1\phi_1\phi_3^{(4)T} & \int_0^1\phi_2\phi_3^{(4)T} & \int_0^1\phi_3\phi_3^{(4)T}\end{pmatrix}d\xi=\begin{pmatrix}\lambda_1^4 & & \\ & \lambda_2^4 & \\ & & \lambda_3^4\end{pmatrix} \tag{11}$$

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

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,

$$B=\begin{pmatrix}2 & -4.75948 & 3.78433\\ 0.75948 & 2 & -6.22218\\ 0.21566 & 2.22218 & 2\end{pmatrix},\ C=\begin{pmatrix}0.8581 & -11.7433 & 27.4531\\ 1.8738 & -13.2942 & -9.04205\\ 1.56453 & 3.22935 & -45.9043\end{pmatrix}$$

Then, by using Eq. (11), after the reduced order through Eq. (10), the discretized equation is shown below, as,

$$I\ddot{Q}+2M_ru_0B\dot{Q}+(CH+\Lambda)Q=0 \tag{12}$$

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, $\dot{Q} = \Omega i$, $\ddot{Q} = -\Omega^2$. Then, Eq. (12) become,

$$\left(-I\Omega^2 + 2M_r u_0 B\Omega i + (CH + \Lambda)\right)Q = 0 \quad (13)$$

Or,

$$\left(-I\Omega^2 + 2M_r u_0 B\Omega i + (CH + \Lambda)\right) = S = \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{pmatrix} \quad (14)$$

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, [22-25], it is possible to evaluate the natural frequency (Ω). The following characteristic equation comes from the expansion of determent above,

$$\Omega^6 - k_5\Omega^5 i - k_4\Omega^4 - k_3\Omega^3 i - k_2\Omega^2 - k_1\Omega i - k_0 = 0 \quad (15)$$

Where, the constants k_0 , k_1 , k_2 , k_3 , k_4 , k_5 depend on the boundary conditions of pipe, and can be using as listed in the Table 1.

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

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

3. Experimental Work

The experimental part will be divided into two main sections. First, the measurement of the natural frequencies of the water conveying pipe at the water pumping station for citizens and for different boundary conditions will be presented. Secondly, the experimental section will analyze the vibration control of water conveying pipe. In this procedure, the data acquisition (DAQ) with the LabVIEW 2018 program will be used, which senses the vibrations by two accelerometer sensors, converted into electrical signals dealh with by the device.

3.1 Test Model

For measuring the natural frequencies and investigating the effect of the water pressure on the natural frequencies, and calculating the dynamic behavior of the pipe for the uncontrolled and controlled responses, Table 2 shows the main specifications of this model.

Table 2. Specifications of the test model.

Material	D_o (mm)	D_i (mm)	E (GPa)
Steel iron	160	153	206

3.2 Water Circuit

In all tests, water was used as a flowing fluid where the pumping system (centrifugal pump) was connected with a discharge capacity (100 m3/ h), a pumping capacity of (10 bar), a lifting capacity of (60 m), then a flow control valve (Butterfly Valve) followed by flexible joint, then check valve (Back - Stop Valve) and a pressure gauge on the water conveyor pipe where water moves through this pipe to filters, as shown in Fig. 1.

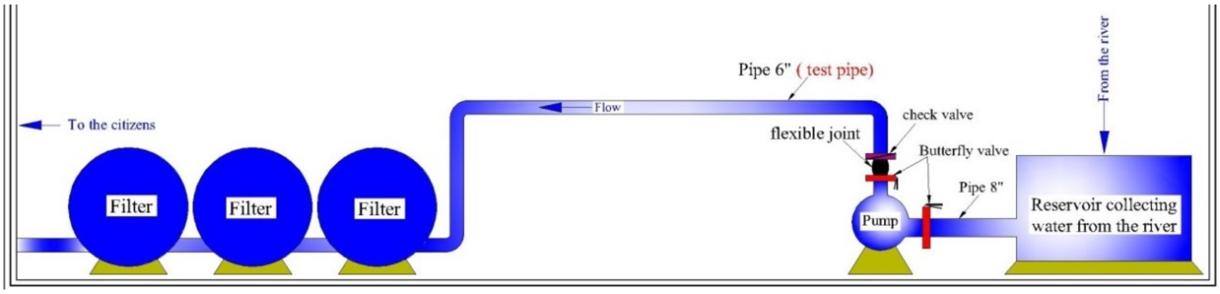


Figure 1. AutoCAD drawing illustrates a schematic diagram of the water circuit.

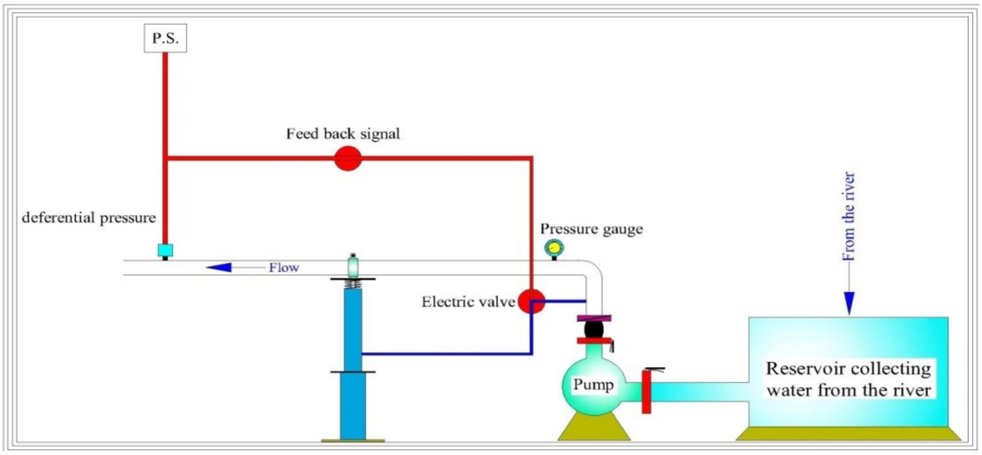
3.3 Experimental Rig

The rig consists of some main parts; centrifugal pump with an electric motor capable of 55 kW that draws water from the collection tanks coming from the river and pushes it through a 6-inch diameter pipe. This pipe is directed towards filters and attached to the pressure gauge and differential pressure. The main pipe is branched out by a 1/2-inch diameter pipe with a gate valve, electric valve, and pressure relief valve. This 1/2-inch diameter pipe is connected to a variable damping pressure according to the signal that comes from the differential pressure and which controls the electric valve as in Fig. 2.a and b.

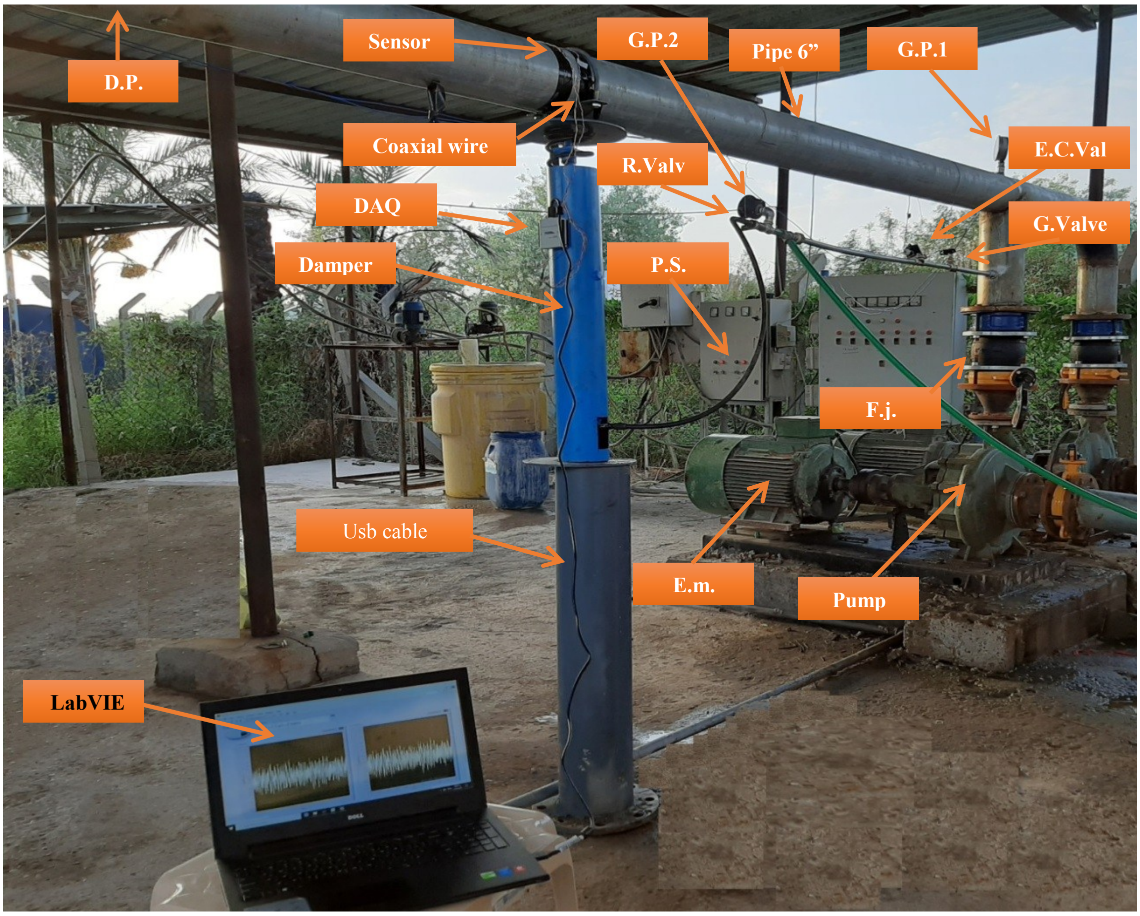
3.4 Instruments Specifications

This will discuss the details of the devices used in the system as follows,

1. Compressor (Pumping) water, this a pump that transfers fluids (water) by converting kinetic or rotational energy into hydraulic energy through this mechanism. Water flows and the pump gets rotational energy from the electric motor connected with it. Impeller water enters the pump near the spindle axis or along the spindle axis and is accelerated by the propellers. The pump that is used is described in the Table 3.
2. Electric motor, an electric motor is placed near the pump and connected to it by a transmission shaft. This motor converts electrical energy into rotational energy. The purpose of this energy is to rotate the pump for the purpose of pumping water. The engine that is used has the specifications below, Table 4.



(a) AutoCAD drawing illustrates a scheme experimental rig.



(b) Parts of the experimental rig.

Figure 2. Experimental Rig.

Table 3. Properties of Compressor Water.

kW	HP	Q (m^3/h)	Head (m)	Inlet (mm)	Outlet (mm)
55	75	240 max-36 min	88.5 max-60 min	225	160

Table 4. Properties of Electric Motor.

Max R.P.M	kW	Hz
1500	55	50

3. Data acquisition device, It is a multi-function, low-cost device with 8 analog inputs and two analog outputs. USB-6009 was used as data acquisition compatible with LabVIEW and uses the NI-DAQmx driver software, called acronym (DAQ) as shown in the Fig. 3. The (DAQ) Toolbox in the LabVIEW program has a full set of tools for analog input, digital I/O, analog output. It can read the data from Accelerometer to the LabVIEW program and the file is saved in xlsx format, [26].
4. Accelerometer sensor, Accelerometer sensor is a tri-axial accelerometer sensor with built-in capacitor coupling between ground and supply voltage, which reduces noise in the line of power supply, as shown in Fig. 4. The implemented accelerometer is ADXL335 (analog type sensor). It has a range in each axis, $+/-3g$. The sensor ADXL335 indicates both static accelerations due to gravity and dynamic acceleration due to movement.

Figure 3. Data Acquisition Device.

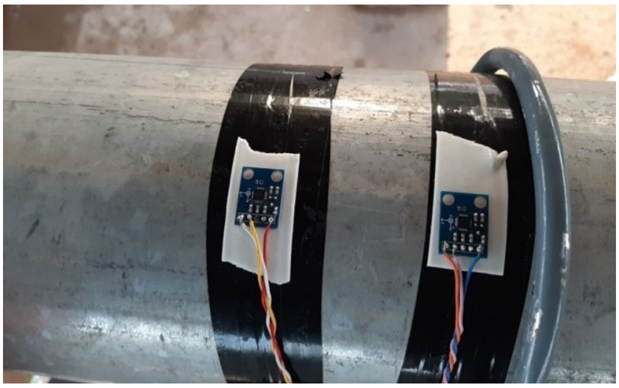


Figure 4. Accelerometer Sensor.

5. Differential pressure, the device converts the pressure difference into an electrical signal through which it opens the electric lock in whole or in part according to what is set. It measures the differential pressure or the difference between two points called Δp. If the pressure at point a = 4.5 bar and at point b = 3 bar, then DP or Δp =1.5 bar. It is an indicator to illustrate the pressure difference generated in the system.
6. Electric control valve, the electric control valve is an electrical device that receives the signal from the differential pressure device and performs the task of closing and opening the whole and partial according to the available data. The specification of the device is Model 2w160-15, volts 220 v, Orifice 15mm, Temp -5 to 100o C, Operating Pressure Min 0 kg/cm^2 to Max 10 kg/cm^2.
7. Gage pressure, It is used to measure the difference of pressure between the surrounding atmosphere and the system. Negative signs are usually omitted. In other words, it is zero-referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure and can be expressed as,

$$P_g = P_{sys} - P_{atm} \tag{16}$$

8. Ultrasonic flow-meter, this device measures the volume of flow in the pipe and thus the speed of the liquid through ultrasound transducers. It measures the rate of flow velocity through the pipe emitted by these waves. This is done by calculating the difference in the time of crossing the pulses generated by the device that propagates with the direction of flow or reverse flow. The waves that are generated can be affected by temperature, the viscosity of the liquid, suspended particles, or density.

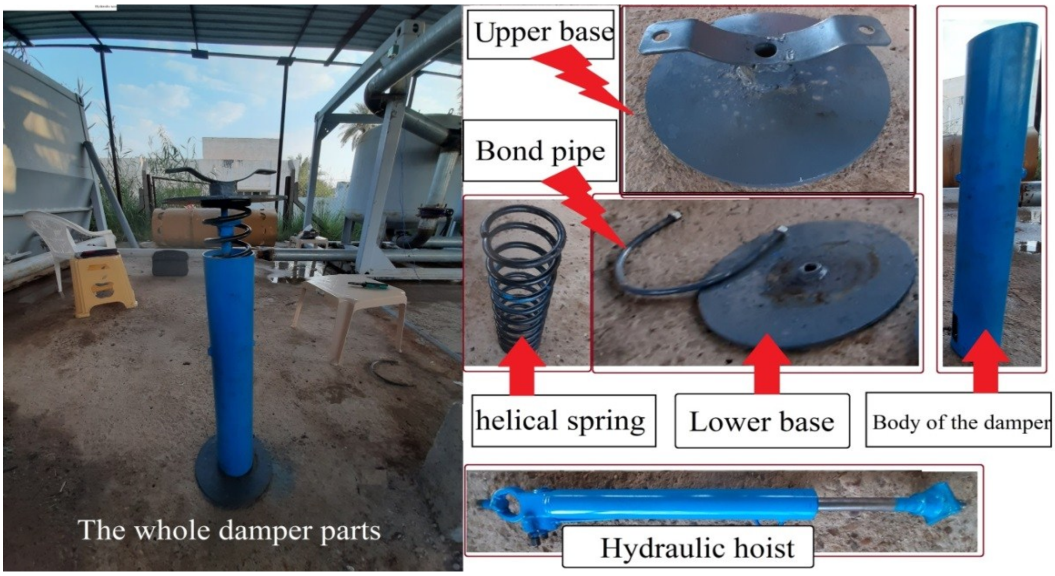
3.5 Damping Tool Parts

Multiple parts were used to carry out the experimental part in the target system where the dampers were used for the purpose of damping the vibration through the variable pressure hydraulic damper and through the spring. The flexible joint was also used at the pump connection point with pipes to reduce the vibrations generated. Flexible joint couplings were used under the pump and the electric motor. Flexible joints at the bottom of the damper were also used to focus on vibrations generated by fluid flow.

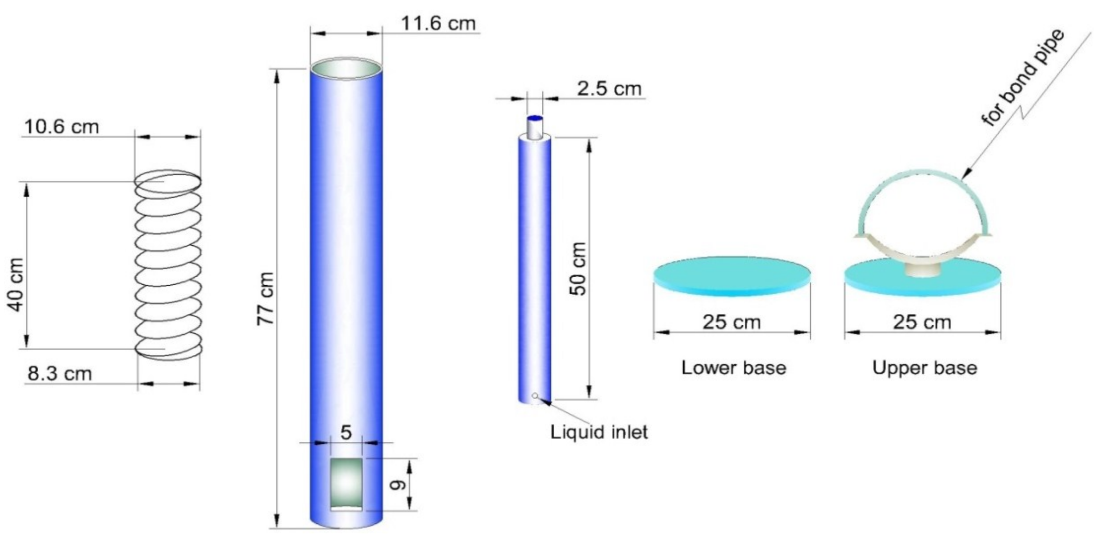
This damper is manufactured for the purpose of damping the vibrations resulting from the flow of water at different pressures and speeds inside the pipes and the vibrations caused by the failure of systems and pipelines as known. Where appropriate, engineering materials and dimensions were chosen to meet the requirements of manufacturing and of damping optimally, as shown in Fig. 5.a and b. Below is an explanation of the damper parts,

1. Hydraulic hoist, which consists of two cylinders. External cylinders are hollow and filled with water or liquid in general, while the interior is rigid and its task of lifting and lowering as a result of fluid pressure changes inside the external cylinder where pressure is generated on the entire cylinder area. For example, when the piston (inner cylinder) is (1 square centimeter) a pressure of magnitude (1 Pa) is applied. The pressure generated on the liquid is (1 Pa per square centimeter). Where the piston whose internal area is (10 square centimeters), a force ten times the previous force is generated. Thus, we conclude; the greater the surface area of the piston, the greater the ability to raise or lower, noting that the Hydraulic hoist is made of stainless steel, as shown in Fig. 6.
2. It is an open helical spring that resists the compressive forces applied to the vertical axis and is used to resist the applied compressive forces, store energy and dissipate it with a vibration system. Spring steel is made of hardened and annealed steel with a very high yield stress of 1,400 MPa (AISI 9255 DIN ، UNI 55Si7 AFNOR 55S7).

Flexible joint is a tool. Its main device to prevent the transmission of vibrations generated in the electric motor and pump to the pipe consists of one part connecting on the pipe out of the pump and the other part is connected to the main tube feeding water. There are many types but do the same purpose and the same principle of work.



(a) Photograph of the damper parts.



(b) AutoCAD drawing illustrates Damper parts.

Figure 5. Parts of the damper.

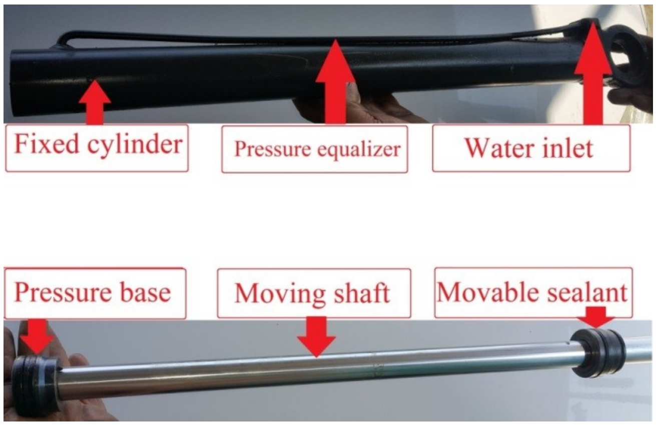


Figure 6. Parts of Hydraulic Hoist.

3.6 Experimental Procedures

The natural frequencies of the pipe are calculated. It is filled with water and again for the pipe which is empty of water with the measurement of the response. The pipe is divided according to the measurements to take readings for regular intervals per 1 meter. After the validation of the results, readings will be taken for different installation cases (Simply support, Fixed for both sides, Cantilever), with different pressures (1 bar, 3bar, 4.5 bar). All the readings were taken by the (DAQ) tool which has good accuracy and different pressures to receive the signals by accelerometer sensors to the LabVIEW program. Then, the measured results are analyzed using the SIGVIEW program to calculate the natural frequency for pipe, [27-31].

A typical length tube was used to conduct the tests with the required installation cases (Simply support, Fixed for both sides, Pinned at one end and fixed at another end, Cantilever). When the pipe is exposed to the fluid flow, resulting from the fluid flow it will be subjected to vibration and the pressure of the pipe bar (1, 3 and 4.5) will be changed. Then, the sensor will measure the response of the model to be displayed in the LabVIEW program. Each time, the pressure is increased and then the vibrations resulting from the flow are measured, for different places of installation and for different pressures. Readings are taken for comparison to get less vibration. LabVIEW stores responses resulting from changing states of compression and fixation in the form of Excel data. The results are then converted to a format that understands the SIGVIEW and Matlab program. The last two programs are used to analyze the results and extract the signal in the form of digital vibrations and determine the natural frequency of each case. SIGVIEW program is an application that receives the data and examine and then analyze and compare between them, [32-35], to implement 2D and 3D drawings for each case of changing the place of installation and change pressure. After analyzing the results, the researcher can find out any ideal and logical situation without reference to the program. Then, after determine the experimental natural frequency results comparison with analytical natural frequency results calculated by using Eq. 15, to given the agreement for experimental work used, [36-39].

3.7 Active Vibration Control Experiments

After connecting the sensors, pressure gauges and water pressure controllers to the power source in the system in question, the active damping system is installed on the pipe model with the differential pressure device set to the desired pressure and connected to a wire that transmits the signal to the electric control valve attached to the feeder pipe of the system damper where it controls the amount of pressure directed to the damper. The differential pressure system is set with two different pressures the first pressure represents the pressure of the water conveying pipe which is the main pipe while the second pressure represents the pressure of the damping system. If the first pressure is set to 4.5 bar, this is the pressure of the pipe. The second pressure was set at 2 bar, which represents the pressure of the damping system. When the first pressure reaches a maximum of 4.5 bar, it gives an indication of the electric valve partial opening of the valve to generate a pressure of 2 bar for the damping system. The damper generates stronger absorption and dissipation forces at high frequency and high amplitude waves. Note that the electric valve is pre-set with a partial opening to check the possibility of receiving the signal to increase the pressure and check the possibility of receiving the signal to reduce the pressure as shown in Fig. 7. By changing the settings of the differential pressure device, the optimum value can be obtained from high pressure and low vibration. High pressure provides good access to water for all citizens. Reducing vibrations increases flow and reduces turbulent flow. Note that optimal damping areas were used at the pipe conveying fluid. Therefore, the experimental control results must be comparison with other control results calculated by other technique, [40-43], then, its results comparison with previous results, [11, 12] and given a good agreement for control results calculated with effect of different flow and damper parameters effect.

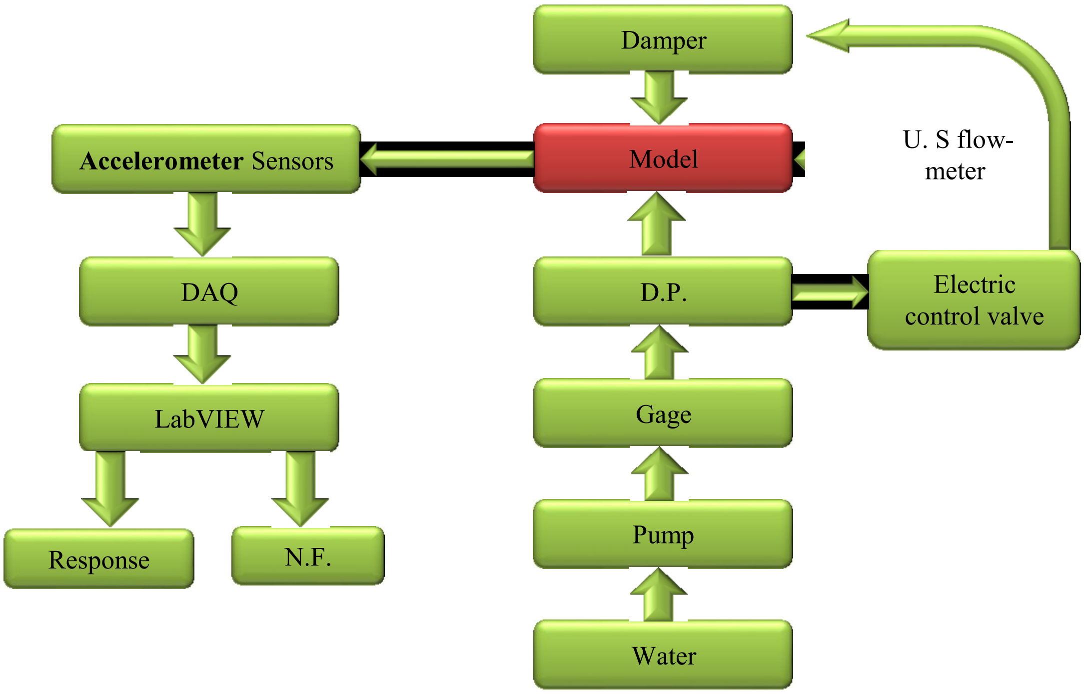


Figure 7. Flow chart of control system experimental.

4. Results and Discussion

The natural frequencies measured for the four cases of fixation of fluid-carrying pipes, pinned-pinned, clamped-pinned, clamped-clamped and cantilever are shown in Table 5, respectively. For the purpose of theoretical comparison and the values corresponding to natural frequencies, the associated errors are shown in the following tables, with good convergence and variation in results. Table 5 show errors between the theoretical and experimental values of frequencies. The reasons for this are,

1. Multiple sources of errors such as the loading of instruments, reading,.. etc.
2. At the pipe inlet, the hose connection adds extra stiffness to the pipe.
3. In practice it is not possible to provide perfect B.C.
4. The plot of the frequency response must be used, for more accurate measuring of the natural frequencies, but such testing requires complex measurement tools.

The Data Acquisition Device is used to calculate the natural frequency of the data obtained by the accelerometer sensor. After analyzing the data through the program Sigview, experimental natural frequencies are obtained for each case of fixation of fluid conveying pipes and with different pressure values. The pressure the pin-pin for fixation of both sides is increased. The natural frequency of the pipe is reduced which means an increase in vibration. This applies to all fixation cases. It is found that the same amount of pressure is the highest natural frequency for the case of (c-c) pipe and then comes the (c-p) pipe, then followed by the pin fixation case from both sides. The lowest frequency is at the case of the cantilever pipe. This means the more constrained the pipe, the less vibration. The normal frequency is inversely proportional to the amount of vibrations. It is clear that if we compare the case of (c-c) pipe and the case of the cantilever pipe, (c-c) pipe will find a greater natural frequency with less vibration, compared to the cantilever pipe. This corresponds to the theoretical part. To take the case of cantilever pipe, which the frequency consists of two parts; the first part is the real value which represents the frequency and the second part is the imaginary value which represents the stability. As the pressure increases, the real part will decrease and this indicates a decrease in the natural frequency, thus increasing vibrations. This is accompanied by a rise in the imaginary part which is an indication of an increase in instability, note the Table 5 and Fig. 8. The general solution offered in Eq. (15), this equation will be validated for conservative pipes. For this, natural frequencies are calculated at $M_r = 0.5$ and $\Pi = 1$ as shown in the results drawn in Figs. 9 to 11, with reference to adding the results of Refs. [44-46], respectively for the same parameters of pipe to the figure mentioned. In these references, shooting methods, Galerkin methods and power series are employed. The other solutions with the present solution are in a good agreement where for the worst case, the maximum error does not exceed 2%.

In Figs. 12 to 17 as shown below, the effects of the fluid velocity for all cases these figures show that the natural frequencies decrease with increasing the fluid velocities and these are real frequencies. Due to the importance of pressure in pipes used in real projects, the effect of pressure on the lowest three modes will be addressed. The Figs. 12 to 14 show the effects of the dimensionless pressure Π, on the three conservative pipes, which are slightly decrease as in these figures with regard to the natural frequencies (Approximately 2%). However, the shape of the curves is not changed. Note that the pressure exert at the pipe ends with a compressive axial force. So it is found that its value is small when compared with other aerodynamic effects for the velocity of fluid where compressive force is arising, as noted in the third expression of Eq.(1). Hence, the natural frequencies will slightly decrease because of this force. For the three conservative pipes, the effects of the mass ratio M_r are shown in Figs. 15 to 17, where the effect of the mass ratio is a slight increase in natural frequencies (Approximately 1%). It means that the Coriolis force effect on the vibrations for pipes conveying fluid (conservative) is not so considerable.

Table 5. Comparison between theoretical and experimental natural frequency results for pipe conveying fluid with various pressure effect, for different boundary condition pipe.

Supported	Pressure (bar)	Natural frequency (rad/sec)		Error (%)
		Theoretical	Experimental	
p-p	1	96.1209	87.2672	9.211
	3	84.5915	77.0519	8.913
	4.5	74.787	67.6433	9.552
c-p	1	154.5263	143.1423	7.367
	3	146.4514	136.0343	7.133
	4.5	140.0902	126.4468	9.739
c-c	1	227.0113	211.6290	6.776
	3	221.217	198.5600	10.242
	4.5	216.7697	191.7566	11.539
Cantilever	1	34.3114+3.7981i	31.0350	9.549
	3	30.9925+5.3173i	27.5443	11.126
	4.5	28.1105+6.4567i	25.7068	8.551

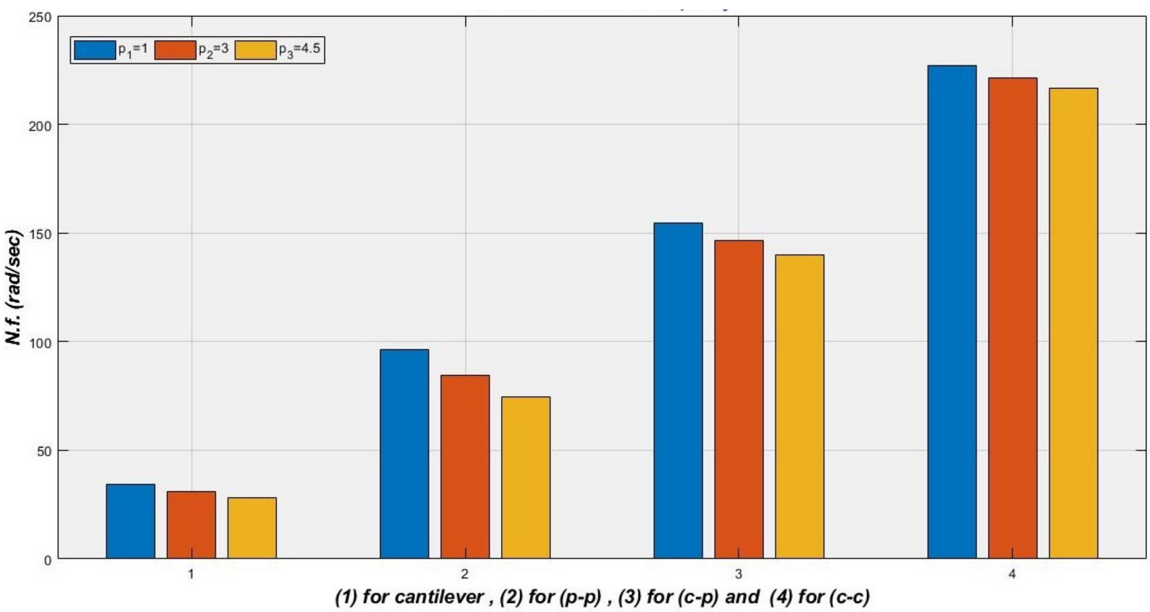


Figure 8. Comparison of different types for fixations.

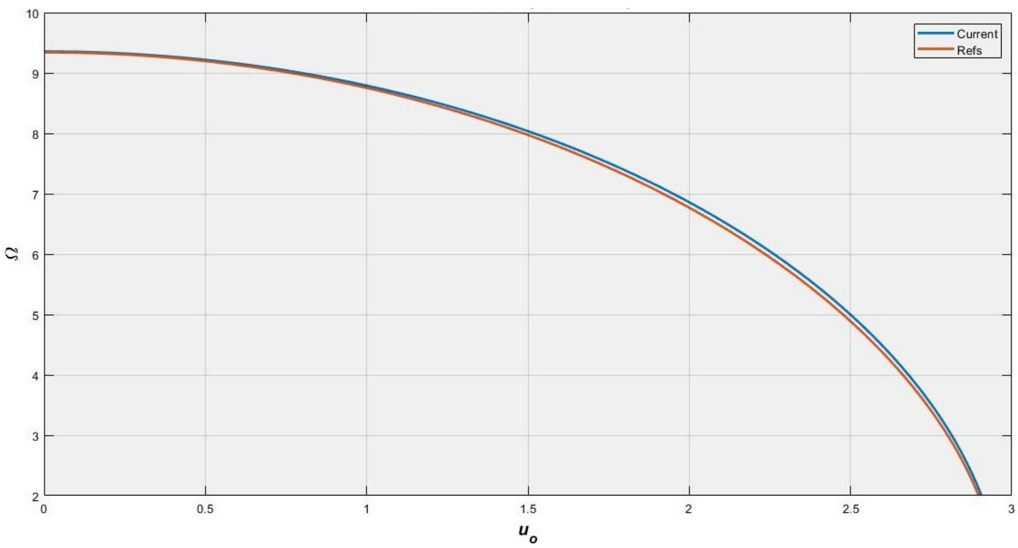


Figure 9. Comparison for Analytical Results with Ref.[44], at $M_r = 0.5$ and $\Pi = 1$ for p-p pipe.

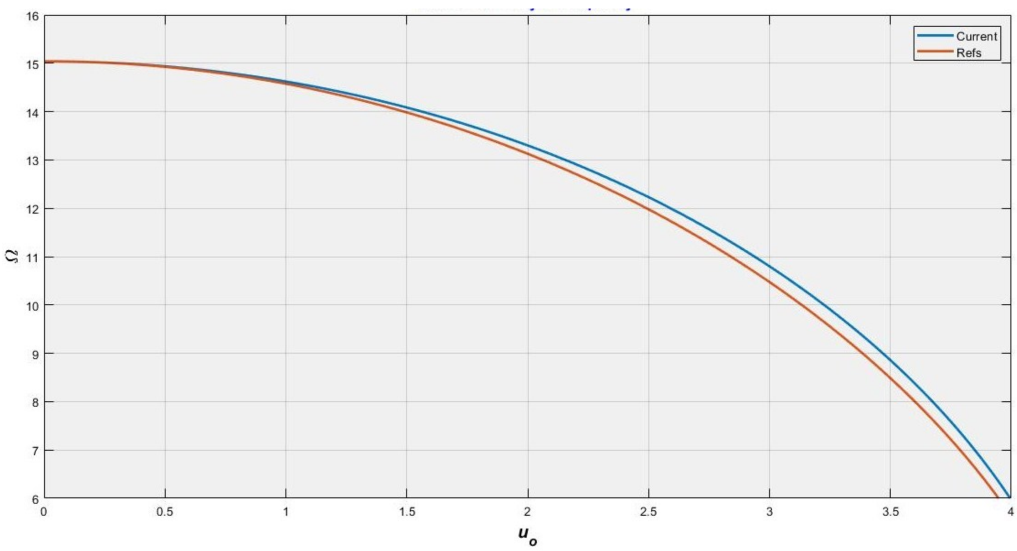


Figure 10. Comparison for Analytical results with Ref. [45], at $M_r = 0.5$ and $\Pi = 1$ for c-p pipe.

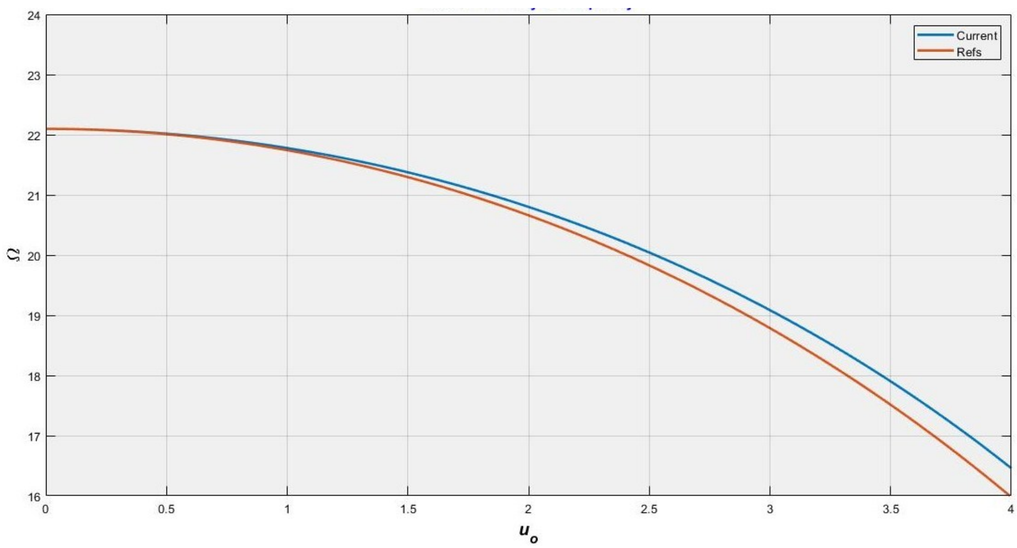


Figure 11. Comparison for Analytical Results with ref.[46], at $M_r = 0.5$ and $\Pi = 1$ for c-c pipe.

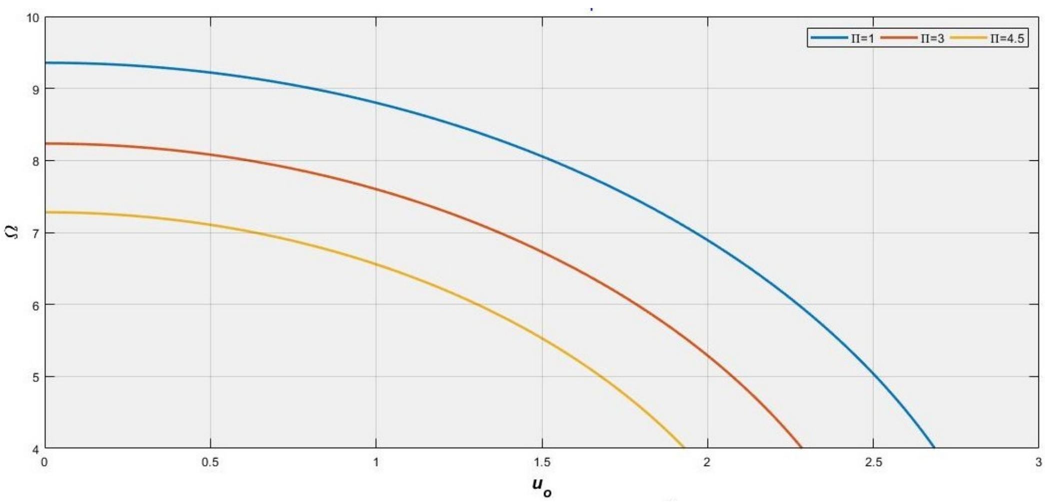


Figure 12. Effect of (Π) on natural the frequencies of pipes conveying fluid, at $\mathrm{M_r} = 0.3697$ for p-p pipe.

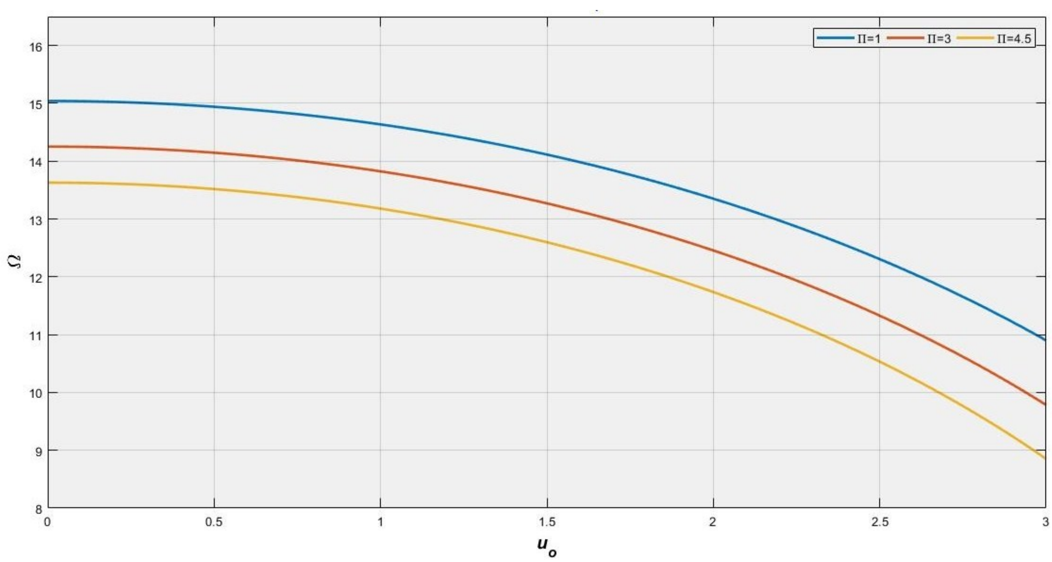


Figure 13. Effect of (Π) on natural the frequencies of pipes conveying fluid, at $\mathrm{M_r} = 0.3697$ for c-p pipe.

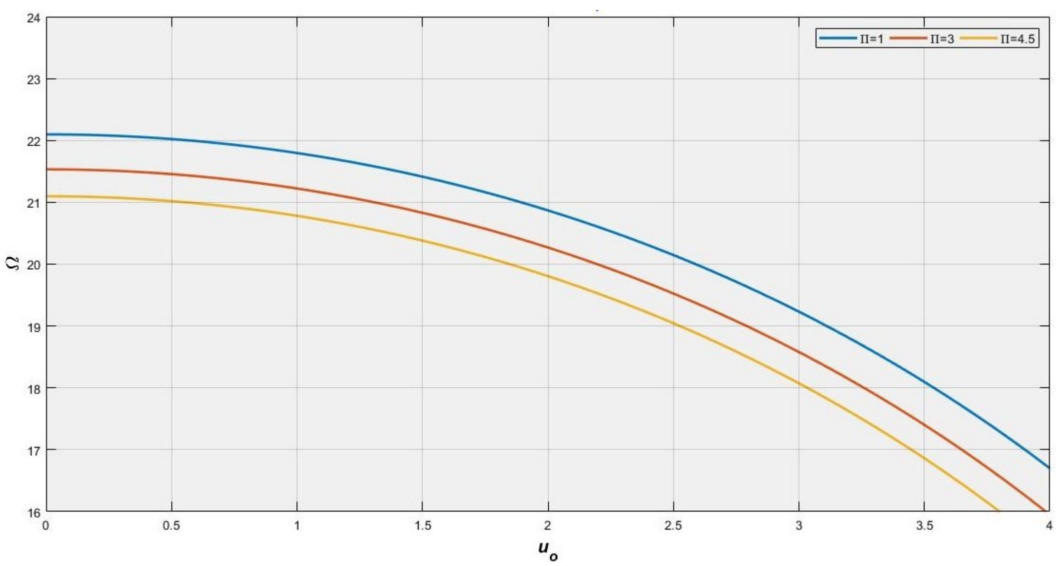


Figure 14. Effect of (Π) on natural the frequencies of pipes conveying fluid, at $\mathrm{M_r} = 0.3697$ for c-c pipe.

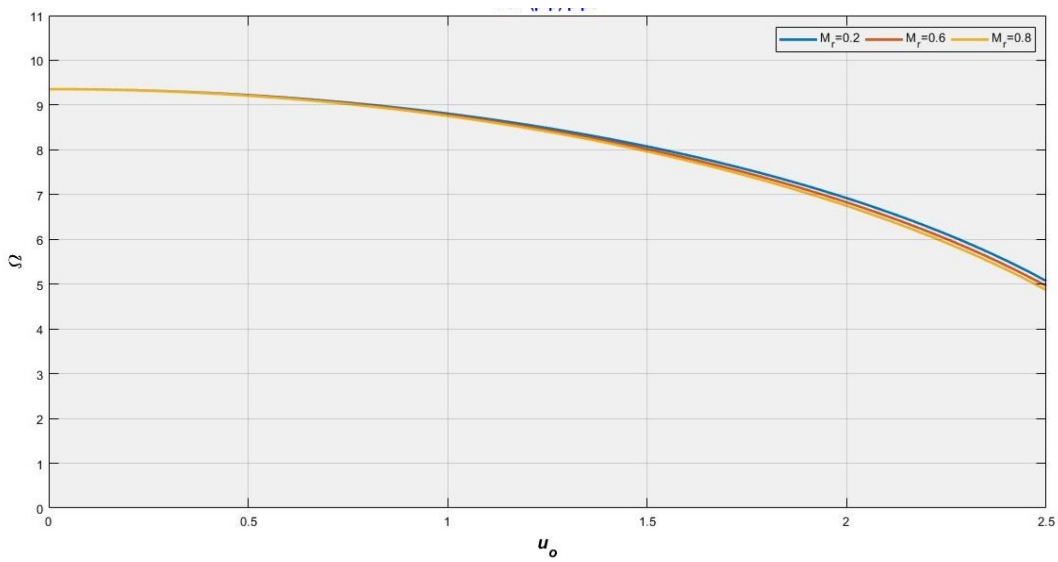


Figure 15. Effect of (M_r) on natural the frequencies of pipes conveying fluid (p-p).

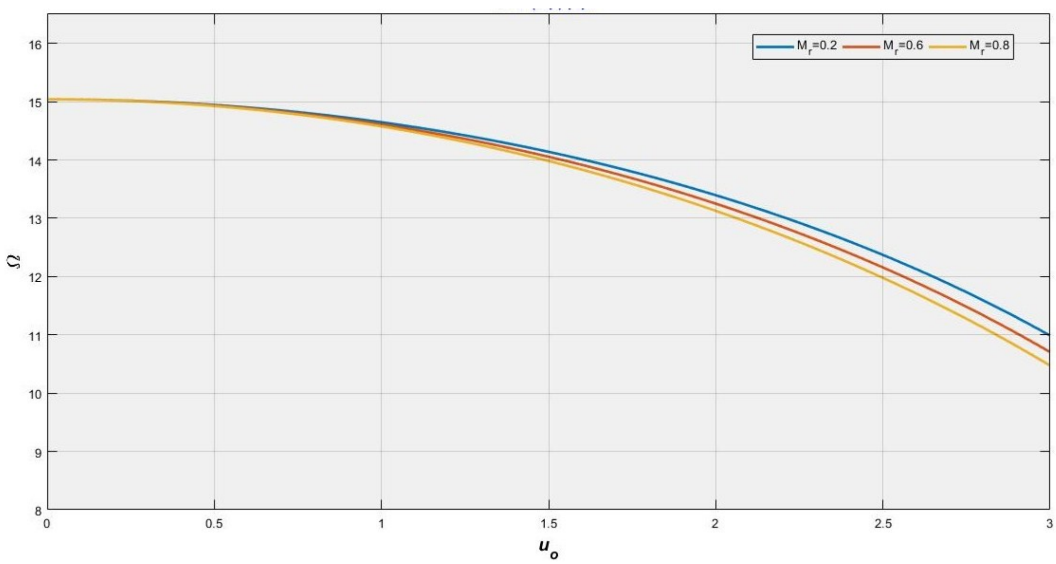


Figure 16. Effect of (M_r) on natural the frequencies of pipes conveying fluid (c-p).

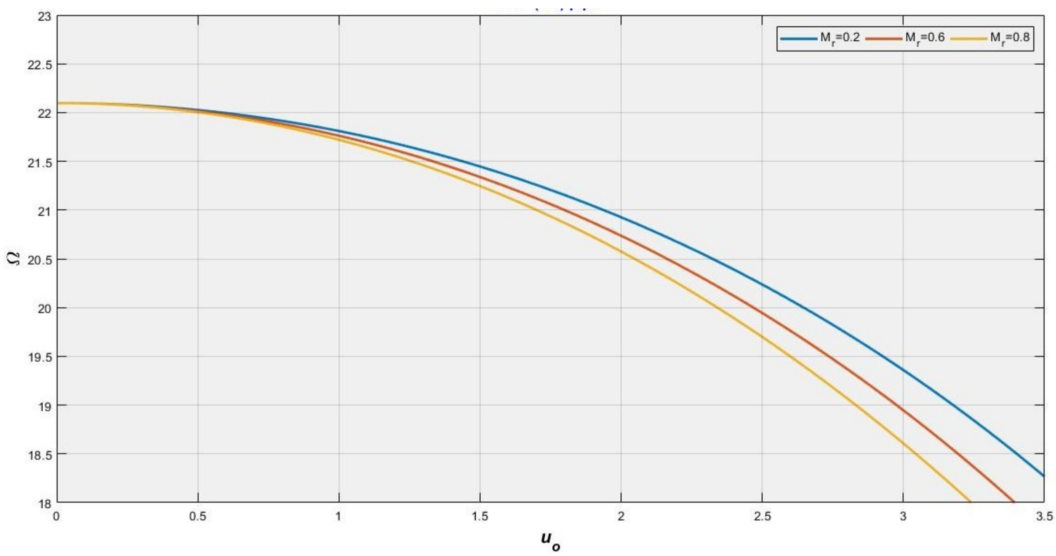


Figure 17. Effect of (M_r) on natural the frequencies of pipes conveying fluid (c-c).

5. Conclusion

From the experimental and analytical techniques used, can be listing the important point for natural frequency results obtained, as,

1. The results are validated by comparing the theoretical results with the results of the previous literature, where the convergence rate does not exceed 2% in the worst cases. In addition, Theoretical results are compared with the experimental results where it is found that the proportion of convergence is acceptable where the error rate in the worst cases is 11.539%.
2. The theoretical side is used to find the natural frequencies of different types of pipes and the results are logical. Also, the results are satisfactory when changing speeds, pressures, mass ratios and many parameters govern the system.
3. There is a very large convergence in the results of control theories used. The results of the change of the parameters of each fixations are compared with each control theory used and a match is found in stability and response.
4. In the experimental aspect, there is little effect on the speed range used, when the speed range increases, the frequency of the pipes will decrease. Also, in the experimental results and simulation of active control, it is found that the location of the hydraulic damper has an effect on the pipe response. The damper is placed at the distances of (1.5, 2 and 2.75) m, respectively, from the fixed end for cantilever pipe. The best performance is found at the damper position near the fixed end. This is due to high strain near the fixed end.
5. The control process is done by differential pressure gauge, where it is set to a certain amount of pressure. When it reaches the specified pressure, it gives a signal to open or close the electric control valve to control the hydraulic damper pressure. In the actual water pumping system, the differential gauge should be set to 5 bar for optimum hydraulic damping performance, to prevent vibrations and increase the ability to control and control the stability of the system.

References

[1] Y. Sun, Y. Gu, H. Xiong ‘Studied and Their Application of Vibration Control Technologies’ International Journal of Computer Science Issues, Vol. 10, Issue 02, No. 2, 2013.

[2] M. J. Jweeg, T. J. Ntayeesh ‘Active Vibration Control Analysis of Cantilever Pipe Conveying Fluid Using Smart Material’ Innovative Systems Design and Engineering, Vol. 06, No. 12, 2015.

[3] C. H. Yau, A. K. Bajaj, O. D. I. Nwokah ‘Active Control of Chaotic Vibration in a Constrained Flexible Pipe Conveying Fluid’ Journal of Fluids and Structures, Vol. 09, No. 01, pp. 99-122, 1995.

[4] Z. Jiao, P. Chen, Q. Hua, S. Wang ‘Adaptive Vibration Active Control of Fluid Pressure Pulsations’ Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, Vol. 217, No. 04, 2003.

[5] Zhen Wang, Yudong Sun ‘experimental research on active vibration control of pipe by inertial actuator and adaptive control’ The 21st International Congress on Sound and Vibration, ICSV21, Beijing, china, 2014.

[6] T. Zhang, H. Ouyang, Y. O. Zhang, B. L. Lv ‘Nonlinear Dynamics of Straight Fluid-Conveying Pipes with General Boundary Conditions and Additional Springs and Masses’ Applied Mathematical Modelling, Vol. 40, No. 17-18, pp. 7880-7900, 2016.

[7] Xin Dekui, Nie Songlin ‘Research on Vibration Control of Hydraulic System Pipeline’ 21st World Multi-Conference on Systemic, Cybernetics and Informatics, 8-11 July, Orlando, Florida, USA, 2017.

[8] Omid Kavianipour ‘Vibration reduction of a pipe conveying fluid using the semi-active electromagnetic damper’ Coupled Systems Mechanics, Vol. 6, No. 2, pp. 175-187, 2017.

[9] Muhsin J. Jweeg, E. Q. Hussein, K. I. Mohammed ‘Effects of Cracks on the Frequency Response of a Simply Supported Pipe Conveying Fluid’ International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol. 17, 05, 2017.

[10] Muhannad Al-Waily, Maher A. R. Sadiq Al-Baghdadi, Rasha Hayder Al-Khayat ‘Flow Velocity and Crack Angle Effect on Vibration and Flow Characterization for Pipe Induce Vibration’ International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol.17, No.5, 2017.

[11] Dhurgham Salah Hussein, Muhannad Al-Waily ‘Active Vibration Control Analysis of Pipes Conveying Fluid Rested on Different Supports using State-Space Method’ International Journal of Energy and Environment, Vol. 10, No. 06, pp. 329-344, 2019.

[12] Dhurgham Salah Hussein, Muhannad Al-Waily 'Frequency Domain Analysis by using the Bode Diagram Method of Pipes Conveying Fluid' International Journal of Energy and Environment, Vol. 10, No. 06, pp. 345-358, 2019.

[13] Muhannad Al-Waily 'Investigation of Health Monitoring of Composite Plate Structures-Using Vibration Analysis' Ph. D. Thesis, Alnahrain University, College of Engineering, Mechanical Engineering Department, 2012.

[14] Muhsin J. Jweeg, Muhannad Al-Waily 'Dynamic Analysis of Stiffened and Unstiffened Composite Plates' The Iraqi Journal For Mechanical And Material Engineering, Vol. 13, No. 4, 2013.

[15] Muhannad Al-Waily 'Dynamic Analysis Investigation of Stiffened and Un-Stiffened Composite Laminated Plate Subjected to Transient Loading' International Energy and Environment Foundation, 2015.

[16] Mohsin Abdullah Al-Shammari, Muhannad Al-Waily 'Analytical Investigation of Buckling Behavior of Honeycombs Sandwich Combined Plate Structure' International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Vol. 08, No. 04, pp. 771-786, 2018.

[17] Diyaa H. J. Al-Zubaidi, Muhannad Al-Waily, Emad Q. Hussein 'Analytical Heat Generation Investigation for Forced Vibration Beam with Different Crack Characterizations Influence' International Journal of Energy and Environment, Vol. 10, No. 01, pp. 33-48, 2019.

[18] Muhsin J. Jweeg, Muhannad Al-Waily 'Analytical Investigation of Time Dependent Tensional Loading of Stiffened and Un-Stiffened Composite Laminated Plates' International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), (TJPRC), Vol. 3, No. 4, 2013.

[19] Muhannad Al-Waily, Zaman Abud Almalik Abud Ali 'A Suggested Analytical Solution of Powder Reinforcement Effect on Buckling Load for Isotropic Mat and Short Hyper Composite Materials Plate' International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol.15, No. 4, 2015.

[20] Muhannad Al-Waily, Alaa Abdulzahra Deli 'A suggested analytical solution of buckling investigation for beam with different crack depth and location effect' International Journal of Energy and Environment, Vol. 7, No. 3, 2016.

[21] Diyaa H.J. Al-Zubaidi, Muhannad Al-Waily, Emad Q. Hussein, Maher A.R. Sadiq Al-Baghdadi 'A Suggested Analytical Investigation of Heat Generation Inducing into Vibration Beam Subjected to Harmonic Loading' International Journal of Energy and Environment, Vol. 09, No. 05, pp. 499-514, 2018.

[22] Muhannad Al-Waily 'Analysis of Stiffened and Unstiffened Composite Plates Subjected to Time Dependent Loading' M.Sc. Thesis, University of Kufa, Faculty of Engineering, Mechanical Engineering Department, 2005.

[23] Muhsin J. Jweeg, Muhannad Al-Waily 'Determination of Inter-Laminar Shearing Stresses Using a Suggested Analytical Solution in the Composite Laminated Plates' International Journal of Mechanical Engineering (IJME), IASET, Vol. 2, No. 5, 2013.

[24] Muhannad Al-Waily 'A Suggested Analytical Solution of Oblique Crack Effect on the Beam Vibration' International Journal of Energy and Environment, Vol. 6, No. 3, 2015.

[25] Abdulkareem Abdulrazzaq Alhumdany, Muhannad Al-Waily, Mohammed Hussein Kadhim 'Theoretical analysis of fundamental natural frequency with different boundary conditions of isotropic hyper composite plate' International Journal of Energy and Environment, Vol. 7, No. 3, 2016.

[26] S. E. Sadiq 'Transient stress analysis on a copper alloy beam' M.Sc Thesis, University of Technology, Iraq, 2016.

[27] Muhannad Al-Waily 'Theoretical and Experimental Vibration Study of Continuous Beam with Crack Depth and Location Effect' Indian Journal of Applied Research (IJAR), Vol. 3, No. 9, 2013.

[28] Abdulkareem Abdulrazzaq Alhumdany, Muhannad Al-Waily, Mohammed Hussein Kadhim Al-Jabery 'Theoretical and Experimental Investigation of Using Date Palm Nuts Powder into Mechanical Properties and Fundamental Natural Frequencies of Hyper Composite Plate' International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol.16, No. 1, 2016.

[29] Muhannad Al-Waily 'Analytical and Experimental Investigations Vibration Study of Isotropic and Orthotropic Composite Plate Structure with Various Crack Effect' International Energy and Environment Foundation, 2017.

[30] Saif M. Abbas, Ayad M. Takhakh, Mohsin Abdullah Al-Shammari, Muhannad Al-Waily 'Manufacturing and Analysis of Ankle Disarticulation Prosthetic Socket (SYMES)' International Journal of Mechanical Engineering and Technology (IJMET), Vol. 09, No. 07, pp. 560-569, 2018.

[31] H. J. Abbas, M. J. Jweeg, Muhannad Al-Waily, Abbas Ali Diwan 'Experimental Testing and Theoretical Prediction of Fiber Optical Cable for Fault Detection and Identification' Journal of Engineering and Applied Sciences, Vol. 14, No. 02, pp. 430-438, 2019.

[32] Muhannad Al-Waily 'Theoretical and Numerical Analysis Vibration Study of Isotropic Hyper Composite Plate Structural' International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), (TJPRC), Vol. 3, No. 5, 2013.

[33] Mohsin Abdullah Al-Shammari, Muhannad Al-Waily 'Theoretical and Numerical Vibration Investigation Study of Orthotropic Hyper Composite Plate Structure' International Journal of Mechanical & Mechatronics Engineering IJMME / IJENS-Vol. 14, No. 6, 2014.

[34] Muhannad Al-Waily 'Analytical and Numerical Thermal Buckling Analysis Investigation of Unidirectional and Woven Reinforcement Composite Plate Structural' International Journal of Energy and Environment, Vol. 6, No. 2, 2015.

[35] Muhannad Al-Waily 'Analytical and Numerical Buckling and Vibration Investigation of Isotropic and Orthotropic Hyper Composite Materials Structures' International Energy and Environment Foundation, 2015.

[36] Muhannad Al-Waily 'Experimental and Numerical Vibration Study of Woven Reinforcement Composite Laminated Plate with Delamination Effect' International Journal of Mechanical Engineering (IJME), IASET, Vol. 2, No. 5, 2013.

[37] Abdulkareem Abdulrazzaq Alhumdany, Muhannad Al-Waily, Mohammed Hussein Kadhim 'Experimental Investigation for Powder Reinforcement Effect on Mechanical Properties and Natural Frequency of Isotropic Hyper Composite Plate with Various Boundary Conditions' International Journal of Energy and Environment, Vol. 6, No. 5, 2015.

[38] Muhsin J. Jweeg, Muhannad Al-Waily 'Experimental and numerical analysis of cross-ply and angle-ply composite laminated plates having various shapes of cut outs' International Journal of Energy and Environment, Vol. 7, No. 6, 2016.

[39] Diyaa H. J. Al-Zubaidi, Muhannad Al-Waily, Emad Q. Hussein, Maher A. R. Sadiq Al-Baghdadi 'Experimental and Numerical Temperature Distribution Study for Harmonic Vibration Beam with and without Crack Effect' International Journal of Energy and Environment, Vol. 10, No. 06, pp. 373-384, 2019.

[40] Muhannad Al-Waily 'Theoretical and Numerical Vibration Study of Continuous Beam with Crack Size and Location Effect' International Journal of Innovative Research in Science Engineering and Technology (IJIRSET), Vol. 2, No. 9, 2013.

[41] Muhannad Al-Waily 'Theoretical and Numerical Study of Natural Frequency Investigation for Orthotropic Unidirectional and Woven Hyper Composite Materials Beam' First International Conference on Engineering Sciences' Applications, ICESA, College of Engineering, University of Kerbala, 24-25 /December, 2014.

[42] Muhsin J. Jweeg, Muhannad Al-Waily, Alaa Abdulzahra Deli 'Theoretical and Numerical Investigation of Buckling of Orthotropic Hyper Composite Plates' International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol.15, No. 4, 2015.

[43] Ehab N. Abbas, Muhsin J. Jweeg, Muhannad Al-Waily 'Analytical and Numerical Investigations for Dynamic Response of Composite Plates Under Various Dynamic Loading with the Influence of Carbon Multi-Wall Tube Nano Materials' International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol. 18, No. 06, pp. 1-10, 2018.

[44] Lin Y. H., Chu C. 'Active flutter control of a cantilever tube conveying fluid using piezoelectric actuators' Journal of Sound and Vibration, Vol.196, pp. 97-105, 1996.

[45] Ashley H., Havilland G. 'Bending Vibration of Pipe Line Containing Flowing Fluid' Journal of Applied Mechanics, Vol. 72, pp. 229-232, 1950.

[46] Wang D. ,Wang C. M. 'A controllability index for optimal design of piezoelectric actuators in Vibration control of beam structures' Journal of Sound and Vibration, Vol. 242, No. 3, pp. 507-518, 2001.