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Vibration Control of a Pipeline using dSPACE

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Abstract

Vibration of a pipeline is being controlled. This pipeline setup is comprised of actuators and sensors placed above and below the pipes. Numerous factors, including human action and nearby motorized equipment, can result in vibrations. Turbulence in flow can also cause vibration in the pipelines. In this instance, the flow creates the disturbance. The piezoelectric sensors are used to detect the vibration. The PID controller simultaneously transmits a control signal through dSPACE to the actuator through which the vibration can be reduced. Using Ziegler-Nichols, a PID controller is designed for the non-linear pipeline for vibration suppression in order to maximize outcomes. The model of the system which includes the dynamics of the structure together with the sensor/actuator dynamics is obtained through the calculations. The performance of PID controller is evaluated experimentally using dSPACE controller board.

Keywords: Vibration Control, dSPACE, Pipelines, Piezoelectric, PID Controller (simulink).

I. Introduction

More than three decades of research in the area of smart structures has shown the viability and potential of this technology. Numerous applications have been suggested, and many of them have been experimentally imagined. Examples include the control of plate and beam vibrations, control of shape and buckling, pipelines and smart skis have been commercially realized. A smart structure has actuators and sensors built into the primary structure and will be controlled by a computer [4].

Piezoelectric materials, which are used in many areas, are one type of adaptive material that can be incorporated with smart structures. Piezo ceramics are an efficient and high-quality actuation and sensing mechanism, and their use as actuators and sensors has significantly grown over the past 20 years. Piezo ceramics has several benefits, including affordability, the lack of moving parts, quick reaction, compactness, and simplicity of use. Compared to other smart materials, problems with signal conditioning, placement, and bonding are simple to solve with piezo ceramics.

Vibration control of pipelines by distributed sensors and actuators has been widely studied in the past decade and more dimensions are introduced to improve the control of structural behavior. The main design approach for systems form is the use of PID controller. One tunes the controller to achieve a satisfactory dynamic response and develops the control signal for the closed-loop system that corresponds to satisfactory dynamic response. One has to design a controller for the states, because these are generally not measurable. This controller delivers the information about the states so that they can be used for control. The PID controller has been one of the most widely used tools for controlling.

Although previous works have clearly shown the tremendous potential of PID, its applications to vibration control of piezoelectric bonded structures have been limited. Therefore, the objective of the present experimental work is to control with PID controller for smart structures. The authors believe that the implementation of PID for vibration control of smart structures in real time using dSPACE is the first of its kind.

II. Experimentation of vibration control

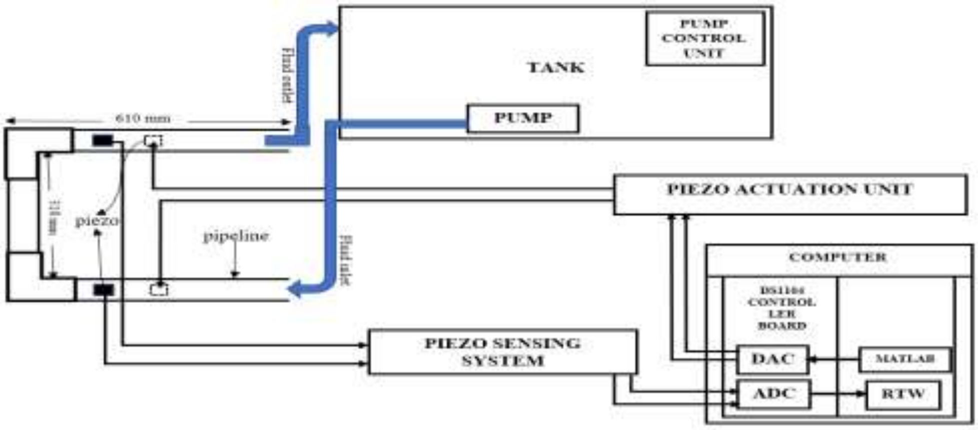


Fig. 2.1 Schematic diagram of the experimental setup

The experimental set up of pipeline vibration control is shown in Fig. 2.1. The input signal is obtained by pipeline vibration due to flowing of liquid. Now, the pipeline is vibrating continuously. The sensors placed at the top of the pipes produce a signal which will be feed to ADC channel of dSPACE. Then, the control action was done by matlab simulink. Then the digital signal feed to the DAC channel of dSPACE to convert it into analog signal which will amplified by piezo actuation system to actuate a pipeline by the piezo placed below the pipes.

III. Hardware Description

A. dSPACE:

The MATLAB Simulink devices rely upon the dSPACE controller board up progressively execution, which is a well-known stage in scholarly exploration. dSPACE is well known controller board, offering many benefits with regards to observing, controlling, and mechanizing tests and making the improvement of controllers more proficient.

The DS1104 controller board with the best reaction as far as a high memory space and quicker execution process was viewed as in this review. The properties of the DS1104 regulator board are made sense of in Fig. 3.1.1.

This figure shows the overall association of the controller board with the PC and the converter (equipment). A photograph of the DS1104 controller board is displayed in Fig. 3.1.2, and the execution stream of the dSPACE-based converter framework is introduced in Fig. 3.1.3.

Ongoing point of interaction (RTI) is the constant reception programming for the dSPACE plot that improves the constant C-code mechanization, impeccably impacts the dSPACE framework and information/yield equipment structure, and naturally makes, amasses, interfaces, and plays out the continuous C-code from the Simulink structure. Besides, RTI produces a variable record relating to signs and boundaries, and Control Desk will contact this document and update the boundaries.

With RTI, one may just run the capability models on the DS1104 controller board. It designs every I/O graphically by pulling RTI blocks and diminishes the execution time to a base. The DS1104 upgrades PCs (laptops) with a solid improvement conspire for quicker control execution.

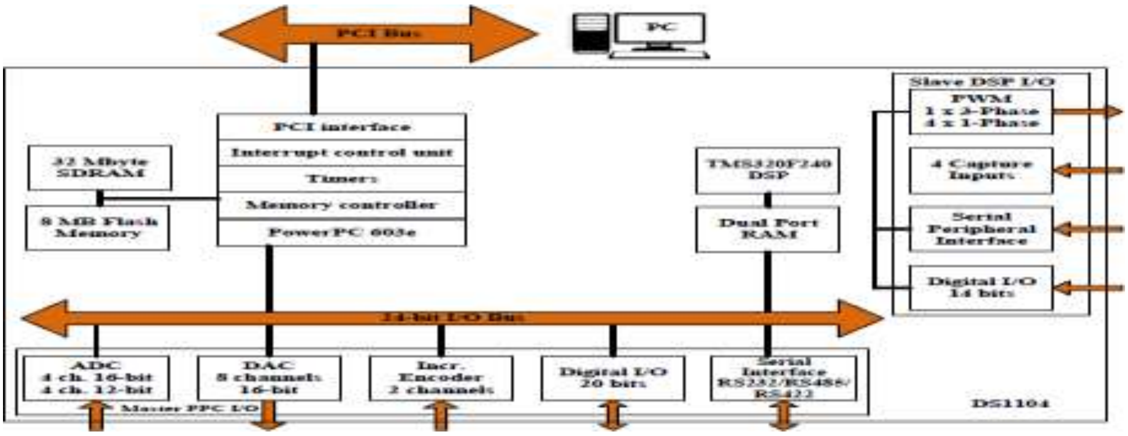


Fig. 3.1.1 Block diagram of the DS1104 controller board.

Fig. 3.1.2 Photo of the DS1104 controller board.

RTI produces Simulink blocks for the graphical construction of a simple to-computerized converter (ADC), an advanced to-simple converter (DAC), I/O lines, and PWM. For the most part, the board might be introduced in every PC with a free 5-V fringe part interconnect (PCI) opening.

There is a prerequisite for the signal conditioning circuits to be handled by means of the dSPACE controller board prior to taking care of the sign. This prerequisite guarantees that the voltage and current signs are determined so that the levels match the ADC input scope of the controller.

Contingent upon the level state of the info, the sign goes through the course of decrease, intensification or current-to-voltage transformation. The signal conditioning comprises of AC voltage and current conditioning circuits, and DC voltage conditioning, as portrayed in Fig. 3.1.4.

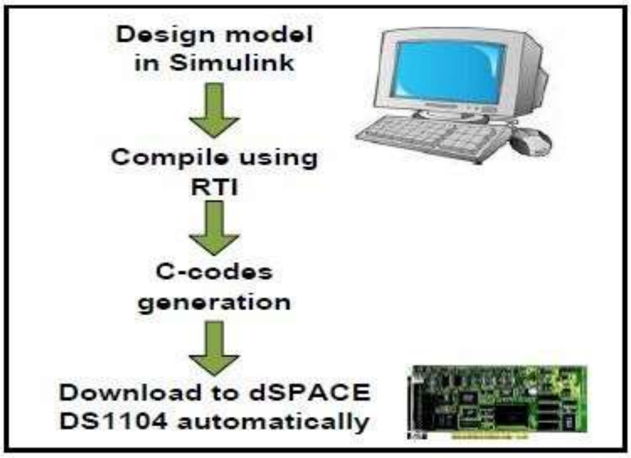


Fig. 3.1.3 Flow of the implementation of the dSPACE-based converter system

The PC should be ready with the dSPACE-related programming and equipment, specifically, the ControlDesk (dSPACE 2008) programming and the DS1104 controller board. Some of the parameters must be measured properly to be set as inputs to the controller. For this reason, the measurement and dissipation circuits are required.

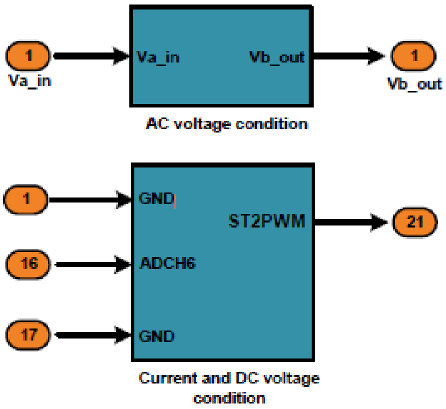


Fig. 3.1.4 Signal conditioning (simulink block).

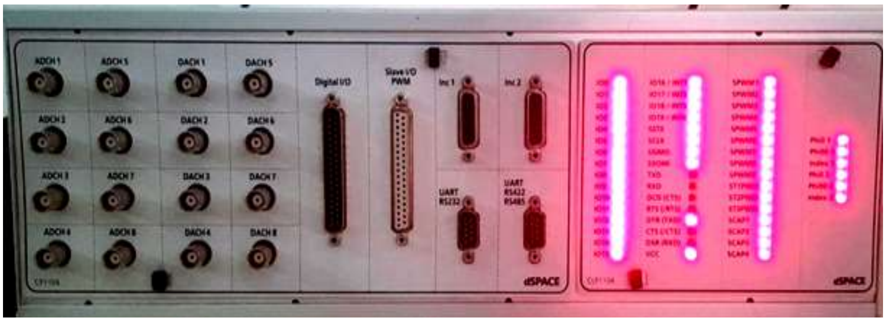


Fig. 3.1.5 dSPACE 1104.

The implementation of the MATLAB/Simulink converter control technique simulated in real time is proficient with the use of the dSPACE DS1104 RTI. In doing so, the required dSPACE input-output library blocks are involved in the control technique. Fig. 3.1.5 shows the dSPACE 1104 card.

B. DESIGN OF PIPELINE:

Plastic pipes with a piezoelectric sensor attached is used in this experiment. The pipeline has three pipes, two pipes have same dimensions and one has different. The pipes are arranged in a way that first pipe, then 90° bend appears, then second pipe, again 90° bend appears and then third pipe is connected which has same dimensions as the first pipe. All three pipes have same diameter. The pipes used in this vibration control experiment is described in Table 3.2.1 in terms of its dimensions and material composition and the transporting fluid through the pipeline is water. Table 3.2.2 shows the transporting fluid properties.

Table 3.2.1 Dimensions and material properties of Pipes

S. No	SYMBOL	PARAMETERS (with unit)	VALUES	
1.	L	Length (m)	Pipe1 & 3	Pipe2
			0.610	0.310
2.	d	Inner diameter (m)	0.011	
3.	D	Outer diameter(m)	0.012	

Table 3.2.2 Transporting fluid properties

S. No	SYMBOL	PARAMETERS (with unit)	VALUES
1.	ρ	Density (kg/m^3)	997
2.	Q	Flow rate (LPH)	420
3.	P	Pressure(psi)	9.26196*10^-8
4.	η	Viscosity(poise) at 20ºC	0.01
5.	T	Temperature(ºC)	20-22

C. PIEZO-ELECTRIC SENSOR:

A piezoelectric sensor is a device which is used to measure the changes in the physical quantity such as (acceleration, temperature, force, etc.) into an electrical quantity (charge). In this project the piezoelectric sensor is fixed to the pipes to sense the vibration occurred in the pipes when it undergoes forced vibration by the flowing of fluid. This signal is passed to the dSPACE to store the data in it and then it is monitored by using MATLAB programming.

Then, the control action was done by matlab simulink. Then the digital signal feed to the DAC channel of dSPACE to convert it into analog signal which will amplified by piezo actuation system to actuate a pipeline by the piezo placed below the pipes. The dimension and material properties of the piezoelectric sensor is given below in the Table 3.3.1.

Table 3.3.1 Dimensions and material properties of piezoelectric sensor.

S. No	SYMBOL	PARAMETERS (with unit)	VALUES
1.	*L*	Length (m)	0.0765
2.	*B*	Width (m)	0.0127
3.	*Ta*	Thickness (m)	0.0005
4.	*Ep*	Young’s Modulus (Gpa)	47.62
5.	*d 31*	Piezoelectric strain constant (mV^{-1})	-247x10^{-12}
6.	*g31*	Piezoelectric stress constant (Vm N^{-1})	-9x10^{-3}
7.	*ρ*	Density (kg/m^3)	7500

IV. Simulation of vibration control

A. SIMULINK:

Simulink is a graphical extension to MATLAB for system design and simulation. Simulink's ability to model a nonlinear system, which a transfer function cannot, is one of its primary advantages. The capacity to take on initial conditions is another advantage of Simulink. When constructing a transfer function, the initial conditions are considered to be zero.

Simulink displays systems as block layouts on the screen. Many block diagram components are available, including transfer functions, summing junctions, and virtual input and output devices such as function generators and oscilloscopes.

Data can be readily transferred between the programs because Simulink is integrated with MATLAB. In these tutorials, we will model the systems, create controllers, and simulate the systems using Simulink and examples from the MATLAB tutorials. Simulink is available on Unix, Macintosh, and Windows platforms, and it is included in the MATLAB student edition for desktop computers.

These lessons are designed to be viewed in one window while Simulink is running in another. System model files can be obtained and opened in Simulink using the tutorials.

These systems can be modified and extended while learning to use Simulink for system design, control, and simulation. Do not mistake the tutorial windows, icons, and menus for your real Simulink windows.

The majority of the images in these tutorials are not interactive; they merely show what you should see in your own Simulink windows. All Simulink actions should be performed within the Simulink windows.

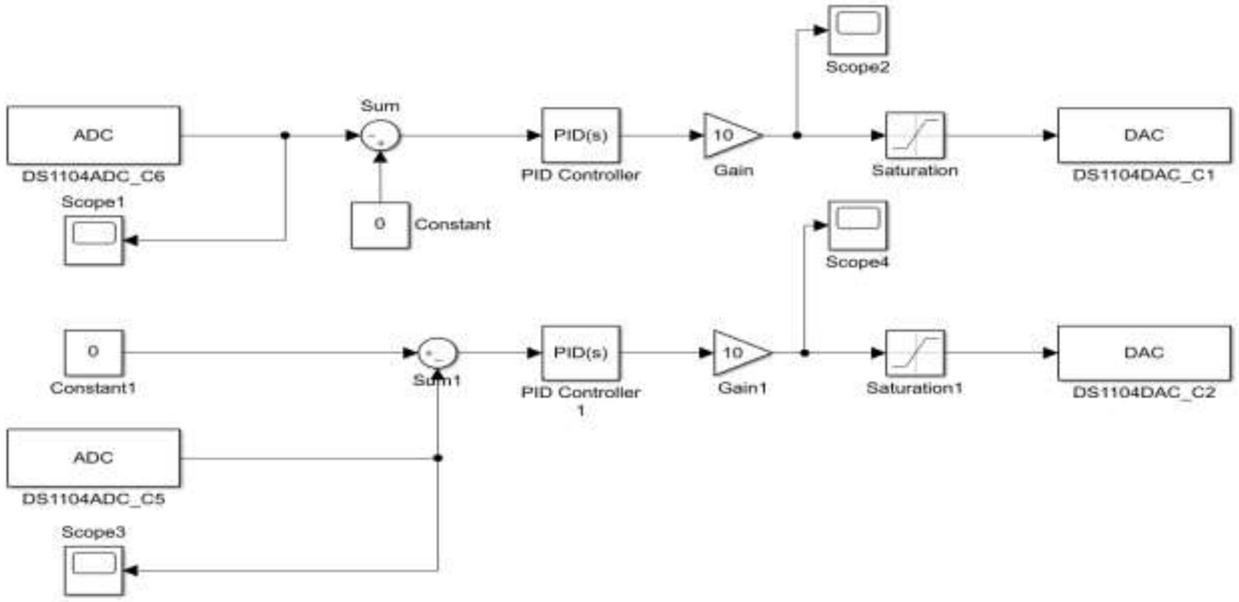


Fig. 4.1.1 Simulink of Vibration Control

B. CONTROLDESK:

The dSPACE experiment software for seamless ECU creation is Control Desk. It handles all of the required tasks and provides you with a unified working environment.

- Integrated ECU calibration, measurement and diagnostics access(CCP, XCP, ODX)
- Synchronized data capture across ECUs, RCP and HIL platforms, and bus systems
- Powerful lay outing, instrumentation, measurement and post-processing (ASAM MDF)

Control Desk unites functionalities that often require several specialized tools.

It can conduct measurement, calibration, and diagnostics on ECUs, for example, via standardized ASAM interfaces, and has access to simulation platforms as well as connected bus systems.

Its adaptable modular structure allows for high scalability to suit the needs of specific application cases. This provides obvious advantages in terms of handling, training requirements, computing capacity, and costs.

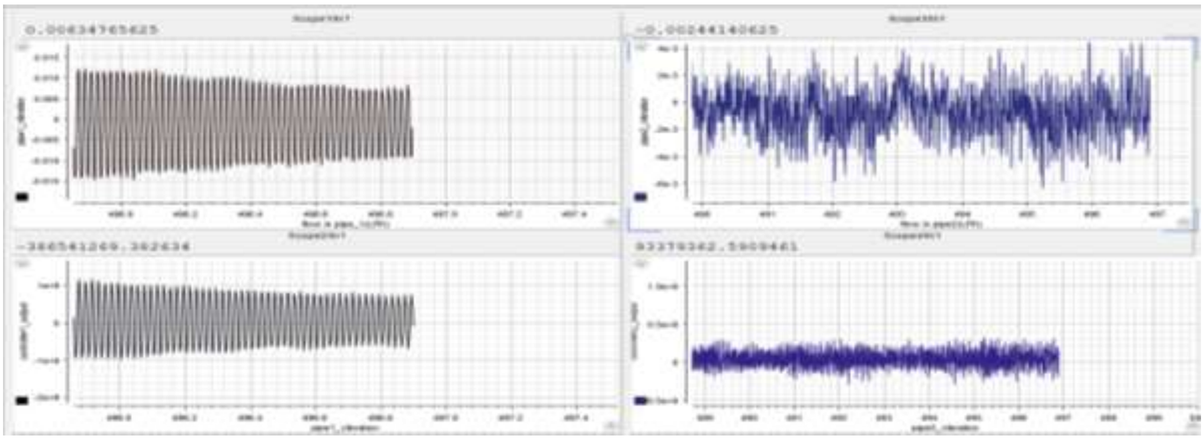


Fig. 4.2.1 Control Desk 7.2 Vibration Control

V. Controller Design

The controller design to suppress the vibration of pipeline involves three steps. Transfer function obtaining, root locus plot and PID tuning using Ziegler-Nichols method.

A. Obtaining transfer function

The transfer function was obtained by using the properties of pipeline and the transporting fluid are substituted in the formulae.

$$\text{Pressure (psi)} = \frac{(Flow\ rate\ (LPH)*0.000264172)}{\left(\frac{(Pipe\ Inside\ Diameter(in))}{2}\right)^2 *3.14159*(Flow\ Velocity^2)}$$

where,

- 0.000264172 is the conversion factor from LPH to cubic inches per second
- 3.14159 is the value of pi.

Flow velocity (ms^{-1})=$\frac{Dividing\ the\ flow\ rate\ by\ cross\ sectional\ area\ of\ pipe}{\pi * radius^2}$

Flow velocity=2852.2263194 ms^{-1} ... (1)

Calculations:

Pipe 1: Length (L1) = 610 mm, Inner Diameter (d) = 11 mm, Outer Diameter (D) = 12 mm

Pipe 2: Length (L2) = 310 mm, same d and D

Pipe 3: Length (L3) = 610 mm, same d and D

Fluid: Water, ρ = 997 kg/m^3, μ = 0.01 Poise

Pressure (P) = 9.26196*10^{-8}psi ... (2)

Flow rate (Q) = 420 Lph

1) Convert units:

Lph to m^3/s: 420 Lph *(1 h/60 min) * (1 min/60 s) * (1 L/1000 cm^3) * (1 cm^3/1000 mm^3) *($10^{-3} m^3/mm^3$) = 4.62 *$10^{-6} m^3$/s

psi to Pa: 9.26196*10^{-8}psi *6894.757 Pa/psi = 0.00638 Pa

2) Calculate Reynolds number for each pipe:

Re1 = (ρVD)/μ = (997 kg/m^3) *(4.62x$10^{-6} m^3$/s) *(π $(0.011\ \mathrm{m})/2)$ ^{2} / 0.01 Poise

= 145640 ... (3)

Re2 and Re3 same as Re1. Since Re > 4000 for all, the flow is turbulent in all pipes.

3) Calculate Darcy friction factor (f) for each pipe using Swamee-Jain equation:

f1 = $(0.25/\log10[(14.8\mathrm{D}/\mathrm{d})\ +\ 0.9(\mathrm{Re}1^{0.5/\mathrm{D}})])^2$

= 0.0307 ... (4)

f2 and f3 same as f1.

4) Calculate head loss in individual pipes:

hl1 = f1 x L1 / d * (V^2/2g) = 0.0307 * 610mm / $0.011\text{m} * (4.62 * 10^{-6} m^3/s)^2$/ (2 * 9.81 m/$s^2$)

= 0.233 m

hl2 = 0.116 m

hl3 = 0.233 m

Total head loss (hl) = hl1 + hl2 + hl3 = 0.582 m ... (5)

5) The transfer function is:

H(s) = hl / (ρgL) = (0.582m) / (997 kg/m^3*9.81 m/s^2* (610mm + 310mm + 610mm) * 10^{-3} m/mm)

= 5.879*10^{-4}

So,the transfer function for the given pipeline is:

H(s) = 5.879 * 10^{-4} ... (6)

Standard form of transfer function = $\frac{5.879 * 10^{-4}}{s^2+2s+1}$ ... (7)

A. Root locus plot

Root locus of the obtained transfer function was plotted using matlab coding and the gain and frequency value was obtained.

Gain (Ku) = 0.340194*10^8 .... (8)

Frequency (ώ) = 1 rad/secs .... (9)

B. Tuning of PID

Tuning of the PID has done using the Ziegler-Nichols method.

Calculations:

Pu=2π/ω=2π/1=6.28

Ku=0.340194*10^8 Pu=6.28 .... (10)

PID tuned values by Ziegler-Nichols method:

Table 5.1 Tuned values of PID

TYPE OF CONTROL	KP	TI	KI	TD	KD
PID	0.6*Ku	Pu/2	KP/TI	Pu/8	KP*KD
	$0.2041164*10^8$	3.14	$0.065005*10^8$	0.785	$0.1602314*10^8$

VI. Experimental Setup/Hardware prototype of pipeline vibration control

The below figure depicts the hardware prototype that has been developed to realize the proposedmethodology. The tests were conducted using the below experimental setup.

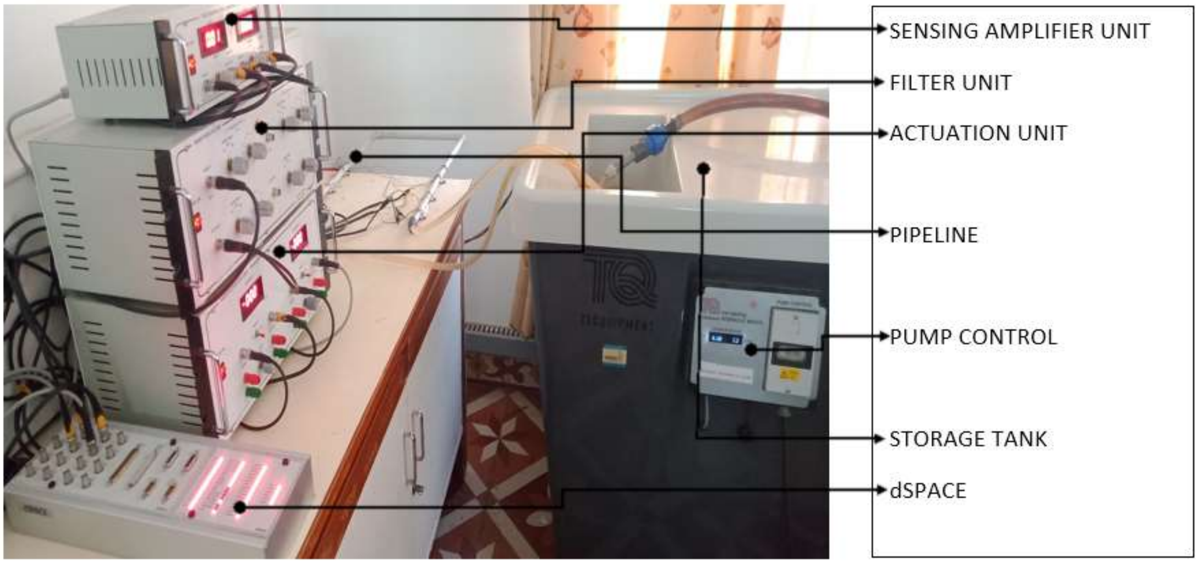


Fig 6.1 Experimental Setup of vibration control of a pipeline using dSPACE.

VII. Operation

A pipeline arrangement with other hardware has shown in figure 2.1 is considered in this paper. Four piezo ceramic patches are surface bonded at a distance of few millimeters from the fixed end of the pipeline. The patchbonded on the top surface of pipe1&3 acts as a sensor and the two on the bottom surface of pipe1&3 act as an actuator. The pipeline vibrates due to flow of fluid inside the pipeline. The vibration in the range of millivolts. The piezo ceramics are electrode with fixed-on adherent silver of solderable quality.

Electrical contacts to the electrodes are made by soldering. This makes fragile piezo ceramics much easier to work with and easier to integrate into the structure. The sensor output is given to the piezo sensing system which consists of high-quality charge to voltage converting signal conditioning amplifier with variable gain.

The conditioned piezo sensor signal is given as analog input to dSPACE1104 controller board. The control algorithm is developed using simulink software and implemented in real time on dSPACE 1104 system using RTW and dSPACE real control block diagrams and real time workshop is used to generate C code from the simulink model. The C code is then converted to target specific code by real time interface and target language compiler supported by dSPACE1104. This code is then deployed on to the rapid prototype hardware system to run hardware in-the-loop simulation. The control signal generated from simulink is interfaced to piezo actuation system through configurable analog input/output unit of dSPACE 1104 system.The piezo actuation system drives the actuator and the excitation signal is applied from simulink environment through a DAC port of dSPACE system.

VIII. Result

The PID controller designed using Ziegler-Nichols in section IV to suppress the vibration. The sensor output is sampled at 0.01 sec through ADC port of dSPACE and MATLAB/simulink to generate a control signal. The output of the controller is compared with the plant constant.

The control signal, comparison between the plant ADC signal and constant. One can see that the output almost matches with the plant output and showing the better performance and ease of implementation with PID using dSPACE. The control signal is generated by multiplying with gain and is applied to the control actuator through DAC port of dSPACE controller board.

The controller is implemented by developing a real time simulink model using MATLAB RTW in simulink. To show the performance of the controller, the pipeline is continuously vibrating due to flow of fluid. Constant (0) given as set point. ADC converts the analog input into digital which will be given by function generator to piezo which was paste on the pipes.

Analog signal was given through ADC channel 5&6 in dSPACE. Constant and ADC signals are compared by comparator. PID continuous controller, which was tuned by Ziegler-Nichols method generates a control signal which was multiplied by a gain (10) to amplify a signal. Saturation point is given as ±5. Digital signals are converted into analog using D/A converter.

Analog signal is taken from the DAC channel 2&1 to suppress the pipeline. The pipe1&3 is only taken for control, totally two pipe that’s why it is mentioned as pipe_1 and pipe_2 in graphs.

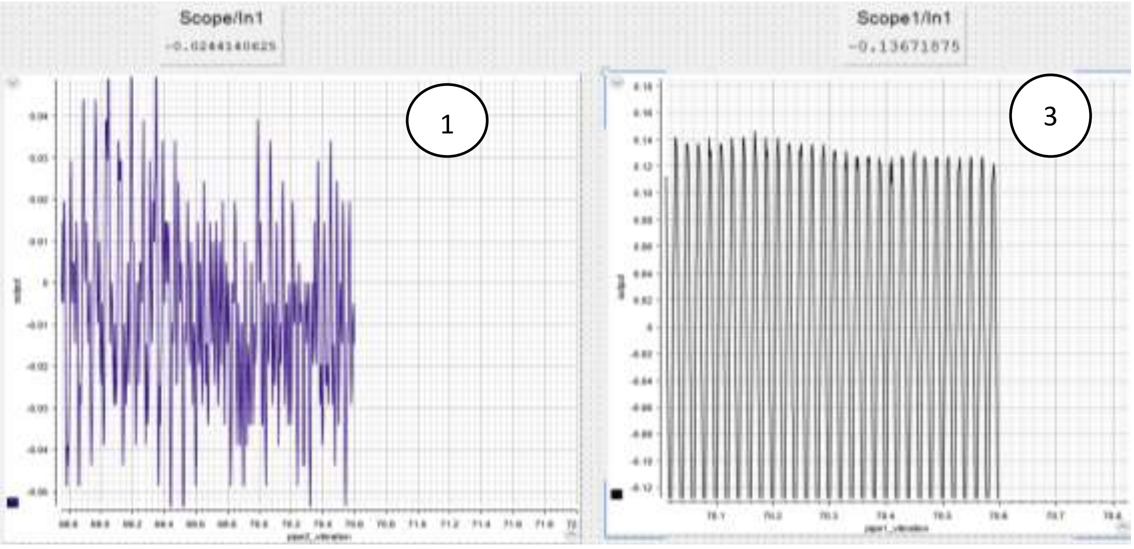
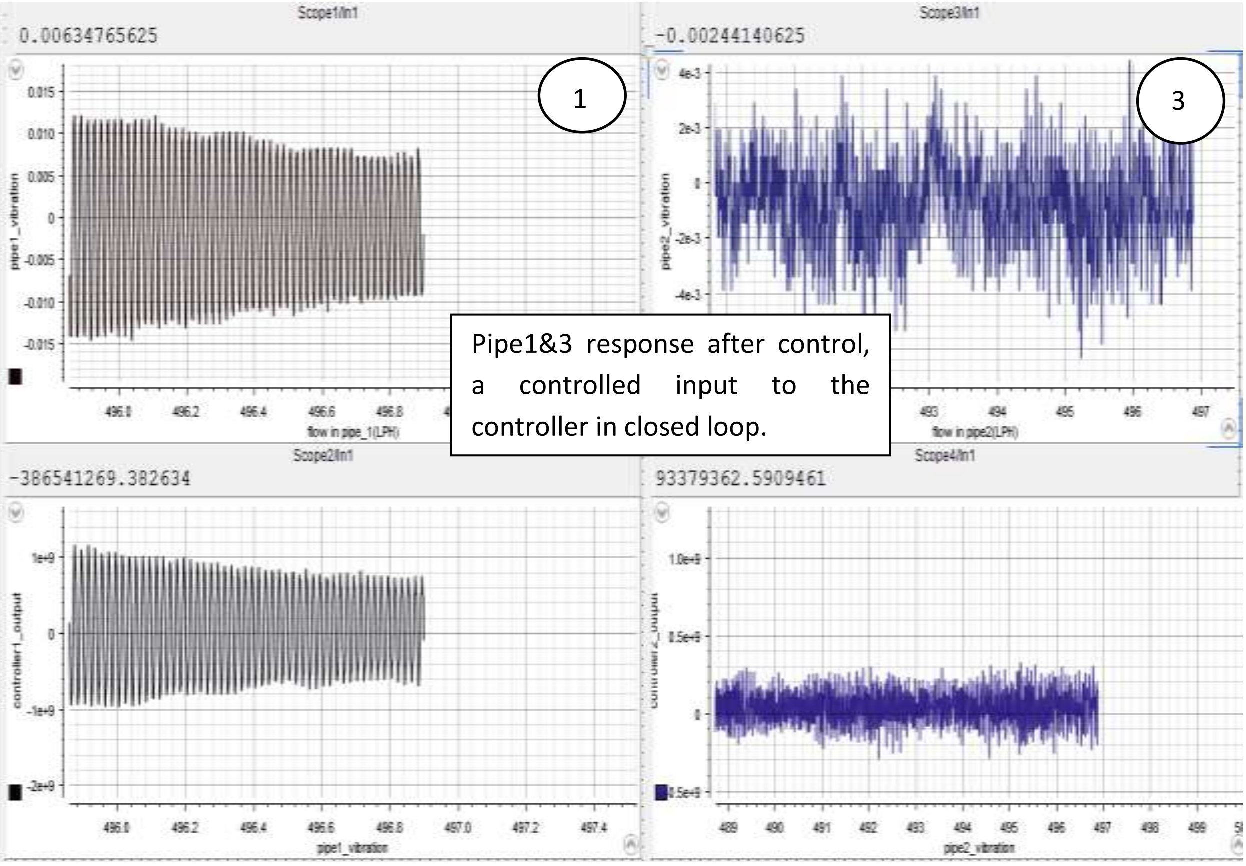


Fig:8.1. Pipes response before control.



Pipe1&3 response after control, a controlled input to the controller in closed loop.

Fig:8.2. Experimental results with PID controller.

XI. Conclusion

This paper presents an experimental evaluation of PID controller for vibration suppression of pipes using the tuned values obtained from Ziegler-Nichols method. From the experimental results it is observed that vibration reduction is 88.48% in inlet pipe and 91.12% in outlet pipe. The experimental results demonstrate very good closed loop performance and simplicity of the PID.

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