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Natural Frequencies Behavior of Pipeline System during LOCA in Nuclear Power Plants

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Abstract—**In nuclear power plants, loss of coolant from the primary system is the type of reduced removed capacity that is given most attention; such an accident is referred as Loss of Coolant Accident (LOCA). Determination of natural frequencies of pipeline system and accurate analysis of their behavior makes the safety management of the system during postulated LOCA or any other accidents. Fast Fourier Transform (FFT) is used for processing the frequency domain signal instead of time domain and the natural frequencies trend is considered to prediction of LOCA in pressurized hydraulic test loop under various pressures experimental conditions. The internal pulse impact is induced by pressure surge due to water hammer phenomenon contemporary with LOCA. The results show that internal stimulation of test loop which is created due to transient mode in fluid can be used to obtain the system's natural frequencies. In addition, with investigation of transient mode during LOCA at frequency domain analysis alternatively, it can be identified LOCA predictably to manage the accident accurately in nuclear power plants.**

Index Terms— **Natural Frequency, Loss of Coolant Accident, Water Hammer Phenomenon, Fast Fourier Transform.**

I. INTRODUCTION

Failure of the components making up a nuclear power plants constitutes one probability of failing during operation, and the plant design has to accommodate these failures while maintaining the integrity of the reactor. In many cases, devices and systems are duplicated or are backed up by other types of systems. In general, the quality of safety-related equipment is required to be unusually high. However, certain types of failures could really put plant systems to the test. Those given most attention, particularly in Pressurized Water Reactor (PWR), are rupture of pipes, particularly in the primary cooling system, and even of the reactor vessel. Extremely stringent materials, fabrication, and inspection requirements are applied to ensure that the probability of vessel rupture is so low as to contribute little risk. The requirements on piping are also high; but it is expected that pipes will fail on rare occasions. However, the safety major objective of nuclear power plants has been required to assess probability of accidence like the LOCA (Loss of Coolant Accident) when the rupture of pipe may occur. The prediction of pipeline rupture is so important; that is included many scientific investigation and experimental implementations. Determination of natural frequencies of pipeline system and accurate analysis of their behavior at the resonation of pipe rupture when it happens; makes the safety management of the system during postulated LOCA or any other accidents.

When LOCA occurred, pressure surges are induced and propagated at speed of sound through the system. This transient response of fluid-filled pipes; usually refereed to as water hammer; involves large transient pressure pulses which can damage the pipe and its components. A completed review on this phenomenon has been presented by As. Tijsseling [1].

In the present study, the excited natural frequencies of a pipeline system caused by water hammer phenomenon during LOCA as a transient mode in fluid which affect on the structure of pipe (Fluid-Structure Interaction) are found and analyzed experimentally in a hydraulic pressure test loop to prediction of LOCA.

R. Mahmoodi et al. [2] presented the finite element method (FEM) as a new method for determination of LOCA in nuclear power plants theoretically. They also used the Fast Fourier Transfer (FFT) as a signal processing method for prediction of LOCA and position of pipe rupture theoretically. Their results show that the mechanical vibration signals caused by LOCA identify the natural frequencies, dominant excitation frequency, and mode shapes in pipeline system.

N. P. Belik et al. [3] reported the natural frequencies of oscillation fluid from the governing equations and considered the determination of the natural frequencies of fluid oscillations in the complex branched hydraulic systems with numerical methods of the basic equations of fluid. They have also analyzed the effect of elastic elements located at the end section of the main pipe on the magnitude of the natural frequencies.

C. B. Sharma et al. [4] considered a method to study the free vibration characteristics of fluid-filled orthotropic cylindrical shells by using of velocity potential function with assumption of no viscous and incompressible fluid in thin shell theory equation. In addition, they used modal forms in the form of Fourier sine or cosine series rather than exponential axial dependence. It is observed that the reduction in natural frequencies decrease with the circumferential number experimental validated results show good agreement with analytical results obtained by Rayleigh-Ritz method, as an approximate technique of finite element method.

Q. S. Li [5] presented the determination of the natural frequencies and mode shapes of non-uniform shear beams

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with classical or non classical boundary condition. He used the basic solutions with unit matrix property and recurrence formula in the governing differential equation for mode shapes of a one-step beam that be reduced.

Laurence Sally et al.[6] used the finite element method or investigation of resonance frequencies and mode shapes theoretically and experimentally. They are considered the flexural and torsional modes for curved pipe geometry and their results show the magnitudes of in-plane vibration relative to magnitudes of out-plant vibration in certain modes.

In this present study, it is considered the three pressure level in hydraulic pressure test loop near the position of pipe's rupture (or opening valve rapidly) experimentally. The results have been obtained in time domain; however it is interesting to prediction of LOCA based on behavior of natural frequencies.

II. Experiments

A. Test Loop

A hydraulic pressure test loop WHTF[1] has been used for investigation of frequency domain analysis of pipe's rupture due to LOCA is based on simple design of the Bushehr nuclear power plant. The experiments presented in this study were conducted to determine dynamic response due to valve opening excitation that simulates water's discharge during LOCA in pipeline suddenly; have been carried out under the pressure. Experimental test loop consists of two cylinders, a circulation pump, pipeline systems, and ball and gate valves. Both of cylinders have made carbon steel with 30 cm inner diameter, 7 mm thickness and 1 m length.

Water in maximum mass flow rate of 1 kg/s is circulating in test loop from horizontal cylinder to vertical cylinder by the pump. For modeling LOCA in order to study suddenly discharge of water; on the connecting pipeline between the pump and horizontal cylinder; a valve has been embedded. Opening of this valve, water can be suddenly discharge of test loop. Fig.1 illustrates a view of this hydraulic test loop. Point C1 shows the location to measurable pipe's vibrations in different pressure near the water's discharge position.

B. Experiment conditions and measurement

To measuring the mechanical vibrations of pipe a pulse analyzer system has been equipped with an accelerometer sensor in 10.2 (mv/g) sensitivity is used to conduct the structural dynamic vibration response to monitoring system and data acquisition. The sampling frequency and sampling rate in this experiment are 25.6 KHz and 2^{16} Hz respectively. The hydraulic pressure test loop operates in atmospheric temperature and instantaneous pressure change will remain above vapor pressure during LOCA, so there is no cavitation during experiments. Pump works in the fixed flow rate, and the generated structural vibration due to rotation of shaft and impeller of this pump will be in background of pipe's structure vibration during discharge of water. Large cylinders with dam acting return back the pressure waves into the pipe

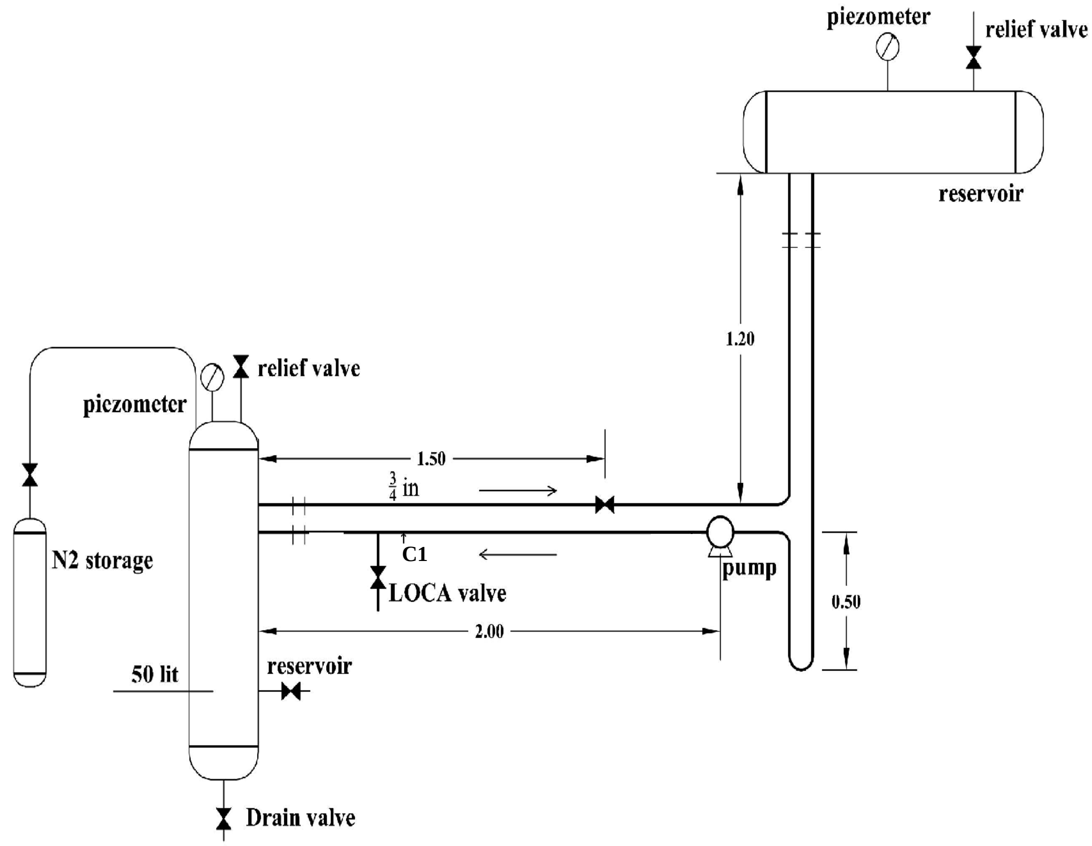

Fig.1: Water Hammer Test Facility

[1] Water Hammer Test Facility

as a pressure vessel in nuclear power plant and attenuating time of there waves will be estimable. Therefore mechanical vibrations generated in the pipe from the water hammer due to sudden valve opening will be clearly measurable.

III. Results and Discussion

A. Time Domain Signals

Pressure waves are generated as a water hammer phenomenon during LOCA. These waves produce mechanical vibrations in pipe. Fig. 2(a) illustrates the time domain vibration of pipe's response at pressure of 8 and 10 bar respectively. The generated dynamic force due to water hammer phenomenon during LOCA; which accelerometer sensor has been sensed in point C1 is included the transient mode. The transient mode in pipeline system can be observed obviously near t_0=3 sec because of water discharge from LOCA valve suddenly. It should be noted that the fluctuations of orifice-induced vibration has been eliminated because of the position of installed sensor. Furthermore, the sensor senses the normal vibration vector of pipe according to Timoshenko theory.

B. Natural Frequencies

The influence of water hammer phenomenon on the mechanical vibration of pipe as a new method for determination of LOCA in nuclear power plant has been considered separately; which obviously show the use of time domain signals for prediction of LOCA. Here, it has investigated the identification of natural frequencies of pipeline system due to water hammer phenomenon in early time of accident. This present study represents the time domain signals by how much information is contained at the frequencies; Fast Fourier Transfer (FFT) provides an alternative way of data representation in frequency domain instead of representing the vibration signal in time domain. Fig. 2(b) and Fig. 2(c) illustrate the frequency domain of pipe's vibration comparatively before transient mode and after attenuating of transient respectively. There is no high excited situation on fluid to excite the natural frequencies of pipeline system as continuous system before or after transient mode.

However when the pressure increases, the excited natural frequencies will be observed difficulty. Table 1 represents the natural frequencies of pipeline system which obtained from FFT analysis of time domain signals accurately. It is noteworthy that although the system's parameters due to difference of velocity of fluid which occurred during LOCA have a shade; but it is ignorable because of constant performance of pump and high volume water in cylinders.

The same frequencies which have been obtained from both states of Fig. 2(b) and Fig. 2(c) can be referred as the natural frequencies of system. 312, 337, and 601 Hz can be presented as three dominant natural frequencies of pipeline system according to Fig.1 which have been obtained from analysis of Fig. 2(b) and Fig. 2(c).

C. Transient Mode Analysis

Water hammer phenomenon or fluid velocity change rapidly is considered as an internal pulse impact that can be excited the natural frequencies of system. The internal pulse impact affects the pipe's structure vibration because of fluid-structure interaction (FSI). In this case, Tijsseling [7] reported a very detailed of review of transient phenomena in liquid-filled pipe system. The main focus was on the history of FSI research in time domain. For precise analysis of natural frequencies of system; with regard to very small time interval of time domain signals, the created transient time interval is analyzed using FFT process partially.

On the other hands, this time interval for transient mode analysis is selected so that the precise analysis can be carried out by FFT processing and supposing the constant parameter of system. As the Fig. 2(a) illustrates the start of event is near t_0=3.00 (Sec) and by counting Δt=0.15 (Sec), the frequency analysis (FFT in Δt=0.15 interval) can be conducted. Fig.3 illustrates frequency domain in 8 and 10 bar respectively at $[t_0, t_0+\Delta t]$, $[t_0+6\Delta t, t_0+7\Delta t]$, and $[t_0+10\Delta t, t_0+11\Delta t]$. One glance at Fig. 3 shows that water hammer phenomenon impact during LOCA excites the frequencies of system. Table 2 lists the first six natural frequencies of pipeline system in transient mode analysis.

IV. Conclusion

The experimental study of structural dynamics has always provided a major contribution of efforts to understanding and to control the many vibration phenomenons encountered in practice. In addition, vibration measurements in combination with frequency analysis are useful when the pressure waves travel and back because of water hammer phenomenon caused by Loss of Coolant Accident (LOCA) in nuclear power plants traditionally.

The important results which are obtained from frequency are analysis as follows:

- Internal stimulation resulted in transient mode of system will stimulate the natural frequencies of this system due to water hammer phenomenon and can be used to obtain the system's natural frequencies.

- As an increased in pressure, amplitude of transient mode in time domain will increased and following the amplitude of

Table 1: Natural Frequencies of Pipeline System (Hz)

Serial No.	In 10 bar (Hz)	In 8 bar (Hz)
1	312	313
2	336	338
3	601	600

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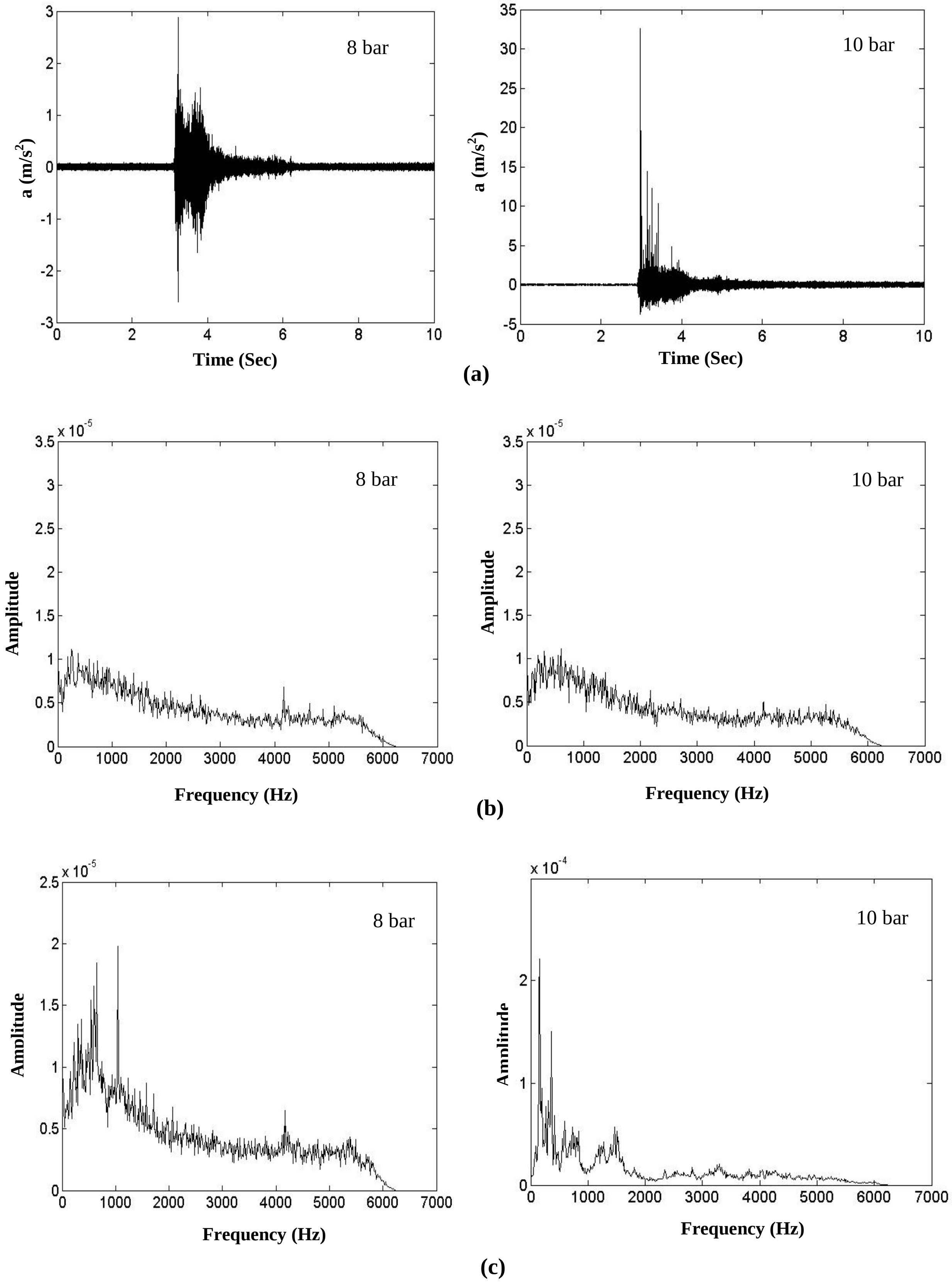

Fig.2: The vibration signal in 8 and 10 bar, (a) Time domain signal, (b) Frequency domain before transient mode, (c) Frequency domain after attenuating of transient.

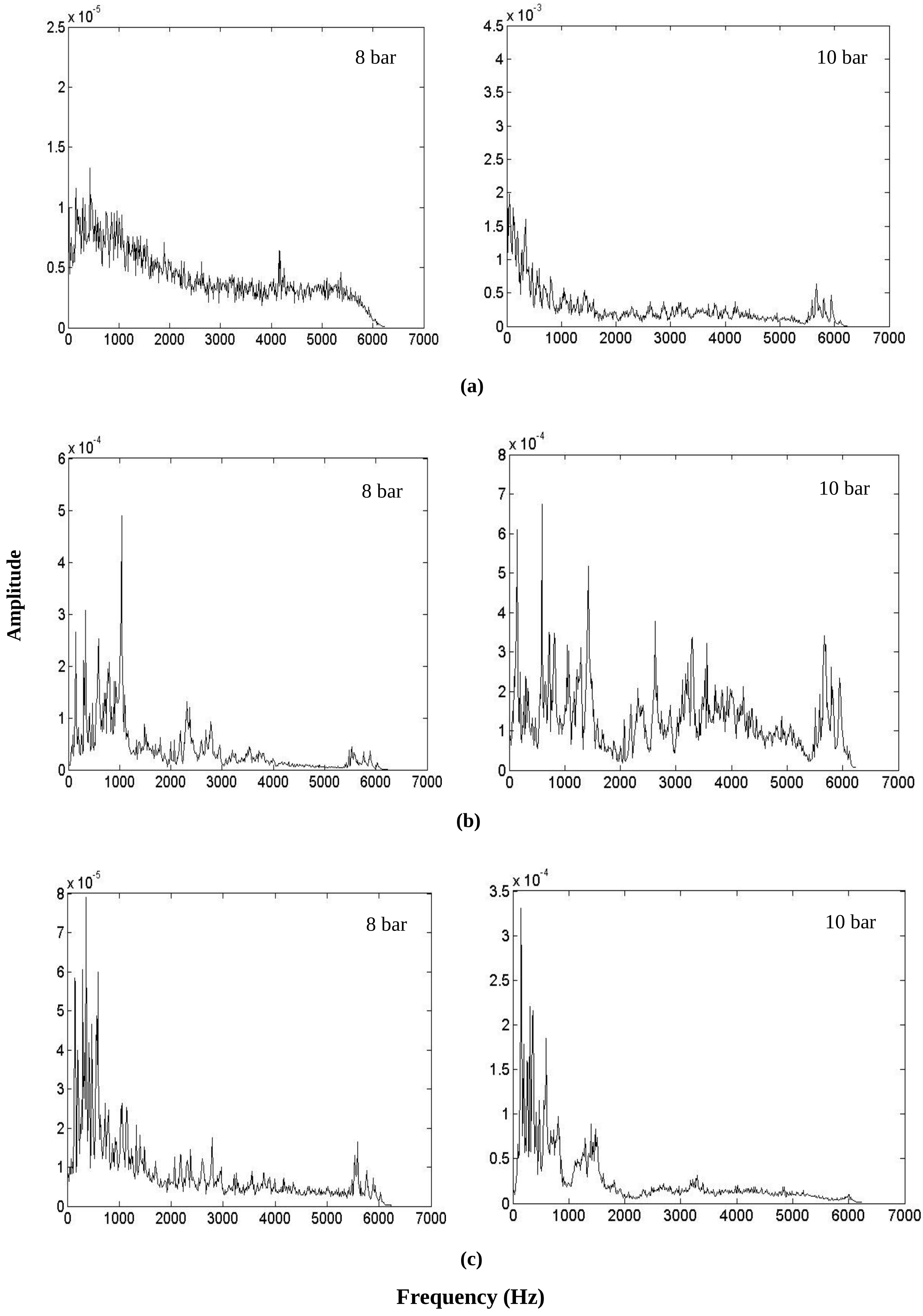

Fig. 3: Frequency domain in 8 and 10 bar, FFT of time domain interval (a) $[t_0, t_0+\Delta t]$, (b) $[t_0+6\Delta t, t_0+7\Delta t]$, (c) $[t_0+10\Delta t, t_0+11\Delta t]$.

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Table 2: Natural Frequencies of Pipeline System in Transient Mode Analysis (Hz)

Serial No.	In 10 bar (Hz)	In 8 bar (Hz)
1	150	150
2	312	313
3	336	338
4	601	600
5	800	800
6	5818	5800

Frequencies increase too. In addition, at attenuating of transient mode, either amplitude of time and frequency domain will decrease.

- With investigation of transient mode during LOCA at frequency domain analysis, it can be identified LOCA predictably to manage the accident accurately in nuclear power plants.

REFERENCES

[1] As. Tijsseling, CSW. Lavooij, "Water hammer with fluid- structure interaction," J. Applied Scientific Research, 1990, Vol. 47, pp. 273-285.
[2] R. Mahmoodi, M. Shahriari, A. Zolfaghari, "Determination of Loss of Coolant accident (LOCA) in Nuclear Power Plants Using Signal Processing Method", Engineering Letters, IAENG International Association of Engineers, 2009, Vol. 17, pp. 305-310.
[3] N. P. Belik, V. A. Makhin, and V. F. Prisnyakov, "Determining the Natural Frequencies of Fluid Oscillations in Complex Pipeline", Mekhanika Zhidkosti i Gaza, 1966, Vol.1, No. 2, pp. 133-136.
[4] C. B. Sharma, M. Darvizeh, and A. Darvizeh, "Natural frequency response of vertical cantilever composite shells containing fluid", Engineering Structures, 1998, Vol. 20, No. 8, pp. 732-737.
[5] Q. S. Li, "A new exact approach for determining natural frequencies and mode shapes of non-uniform shear beams with arbitrary distribution of mass or stiffness", International Journal of Solids and Structures, 2000, Vol. 37, pp. 5123-5141.
[6] Laurence Salley, Jie Pan, "A study of the modal characteristics of curved pipes", Applied Acoustics, 2002, Vol. 63, pp. 189-202.
[7] AS. Tijsseling, "Fluid-Structure interaction in liquid-filled pipe systems: a review," J. Fluids Struct. 1996. Vol. 10, pp. 109-146.