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Vibration Analysis of the BAEC TRIGA Research Reactor Cooling System: A Comprehensive Study

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Abstract: The Bangladesh Atomic Energy Commission (BAEC) Research Reactor (BTRR) cooling system is a critical component for safe and reliable reactor operation. Excessive vibration of this system can lead to fatigue, component failure, and potential safety hazards. This paper presents a comprehensive investigation into the vibration characteristics of the BRR cooling system, including a detailed analysis of the system's design, operation, and potential sources of vibration. Experimental measurements were conducted at various locations within the system to characterize the vibration levels and frequencies. Based on analytical results, it is found that the mitigation strategy (variable frequency device installation, providing soft start up, change of coolant pump motors, change of piping arrangements, provide piping supports) is quite successful as the vibration level reduce significantly. specially for the primary side the vibration improvement was observed up to 75%. Reduction of vibration in primary side is very important in context of loss of coolant accident prevention. This study aims to provide a roadmap for improving the vibration performance of the BTRR cooling system, enhancing its reliability, and contributing to the overall safety of the reactor.

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I. INTRODUCTION

Research reactors play a vital role in scientific research, isotope production, and training in nuclear technology. BTRR, like other reactors of its kind, generates significant heat during operation, necessitating a robust cooling system to maintain safe operating temperatures and prevent core damage [1]. This cooling system typically consists of pumps, piping, heat exchangers, and supporting structures. The reliable operation of this cooling system is paramount for the continuous and safe utilization of the reactor.

However, these cooling systems are often subjected to various vibration sources, including pump-induced pulsations, flow-induced vibrations, mechanical imbalances, and external sources [2]. Excessive vibration can lead to several detrimental consequences, such as Fatigue Failure, Component Damage, Noise Pollution, Operational Instability, Safety Hazards etc.

Prolonged exposure to cyclic stress caused by vibration can initiate and propagate cracks in critical components like piping and supports, leading to catastrophic failure [3]. Vibration can accelerate wear and tear on rotating equipment, such as pumps and motors, reducing their lifespan and increasing maintenance requirements [4]. Excessive vibration can generate unwanted noise, creating an uncomfortable working environment for reactor personnel [5]. In severe cases, vibration can affect the stability of the reactor system and potentially lead to unplanned shutdowns. Ultimately, component failure due to vibration can compromise the safety of the reactor and the surrounding environment [6].

Therefore, understanding the vibration characteristics of the BRR cooling system and implementing effective mitigation strategies is crucial for ensuring the reactor's safe and reliable operation. This research paper presents a comprehensive investigation into the vibration behavior of the BRR cooling system, aiming to identify potential vibration problems, propose mitigation strategies, and validate their effectiveness.

II. DESCRIPTION OF THE BTRR COOLING SYSTEM

BTRR cooling system is designed to remove the heat generated during reactor operation and maintain the reactor core at a safe operating temperature. The system consists of a primary cooling circuit and a secondary cooling circuit

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associated with online purification system and emergency core cooling system (ECCS) which has been illustrated at figure 1. The primary circuit circulates coolant directly through the reactor core, while the secondary circuit dissipates the heat from the primary circuit to the environment.

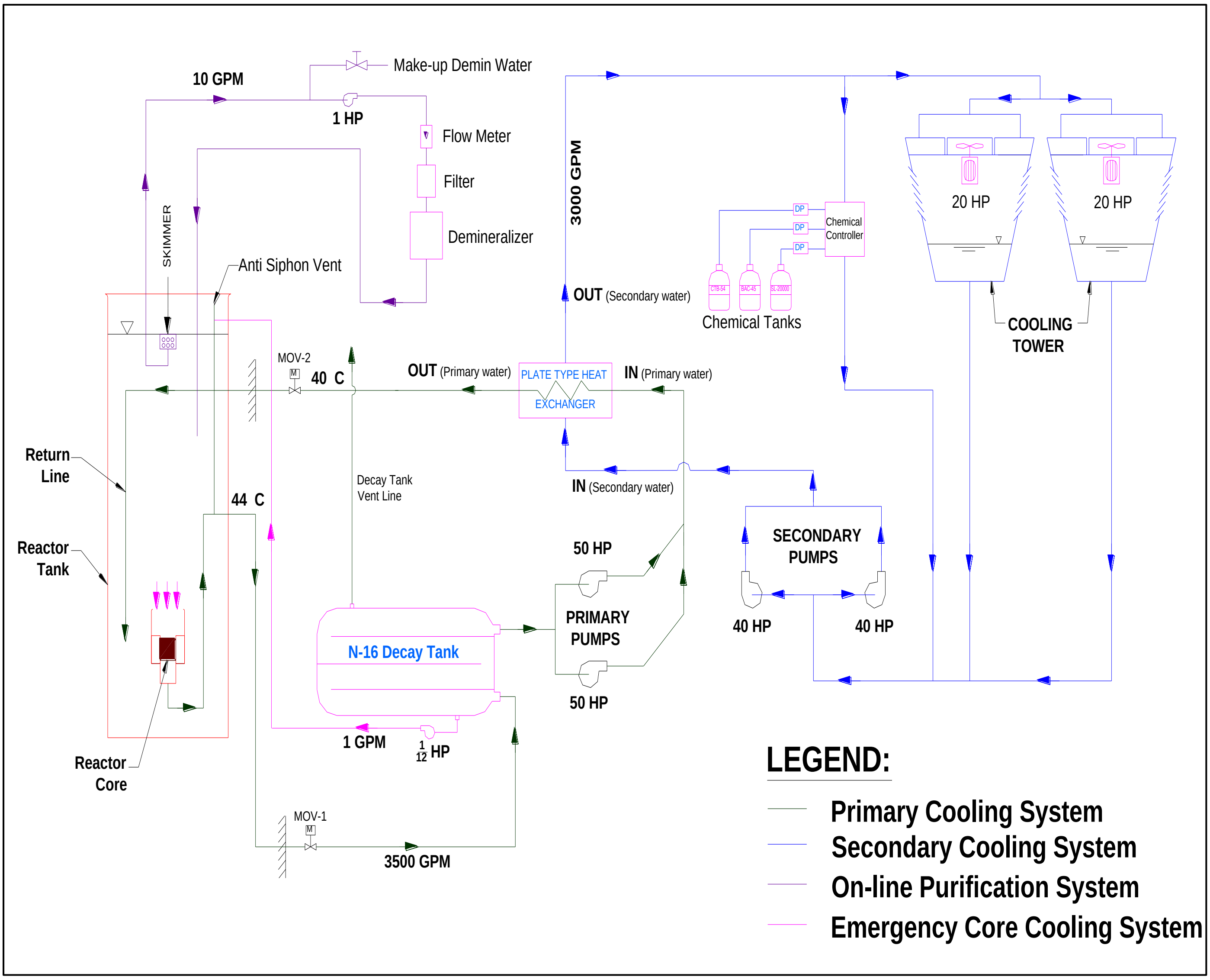

Fig 1 BTRR colling system schematic diagram.

A detailed description of the BRR cooling system is essential for understanding the potential sources of vibration and the critical components that may be susceptible to vibration-induced damage. This includes:

- *Pumps:*

The primary and secondary coolant pumps are the primary drivers of fluid flow in the system. Their operating characteristics, such as flow rate, pressure head, and rotational speed, directly influence the vibration behavior of the piping and other components. BTRR coolant system consists 2 nos primary pumps having capacity of 50HP of each pump and 2 nos 40 HP secondary pumps to drive the coolant through the piping systems.

Fig 2 BTRR Colling Pumps.

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➢ *Piping:*

The piping network transports the coolant throughout the primary and secondary system. The geometry, material, and support structure of the piping influence its natural frequencies and its susceptibility to flow-induced vibration.

Fig 3 Piping Network of BTRR Colling System.

➢ *Heat Exchanger:*

Heat exchangers transfer heat from the primary coolant to the secondary coolant. BTRR facility consist a plate type heat exchanger having $7MW_{th}$ capacity.

Fig 4 Heat Exchanger of BTRR Colling System

➢ *Valves:*

Valves control the flow of coolant within the system. Their operation, particularly sudden opening or closing, can generate pressure surges that excite vibration.

➢ *Support Structures:*

The supports for the piping, pumps, and heat exchangers play a critical role in mitigating vibration. The stiffness and damping characteristics of the supports influence the system's overall vibration response.

Several modification works have been carried out from time to time to improve the performance of the coolant system of BTRR. These includes but not limited to modification of coolant piping system, introduction of variable Frequency Drive (VFD), replacement of old pump motors, replacement of heat exchanger etc.

III. POTENTIAL SOURCES OF VIBRATION

Several factors are responsible for generating vibration in the BTRR cooling system. An overestimation in the BTRR pump size implies potential inefficiencies within the system. This over-design leads to increased capital expenditure, elevated operational costs associated with unnecessary energy consumption, and potential system instability due to suboptimal pump performance. To minimize the flow within the desired limit, throttle valves has been installed in the downstream of the pumps which is a prime source of vibration. The rotating components of the pumps, such as the impeller and motor, can generate periodic forces that excite the surrounding structures. Factors such as impeller imbalance, cavitation, and bearing defects can exacerbate pump-induced vibration. In addition, the flow of coolant through the piping network can induce vibration due to various mechanisms, including turbulent flow, which generates fluctuating pressure forces on the pipe walls, which can excite vibration. Rotating equipment, such as pumps and motors, may have inherent mechanical imbalances also generate vibration at the rotational frequency.

IV. EXPERIMENTAL VIBRATION MEASUREMENT

To characterize the vibration behavior of the BTRR cooling system, a comprehensive experimental measurement program was conducted. This involved the selection of strategic measurement locations, the deployment of appropriate sensors, and the acquisition and analysis of vibration data.

➢ *Measurement Locations:*

Measurement locations were selected based on the system's geometry, operating conditions, and potential vibration sources including motor and pump casings.

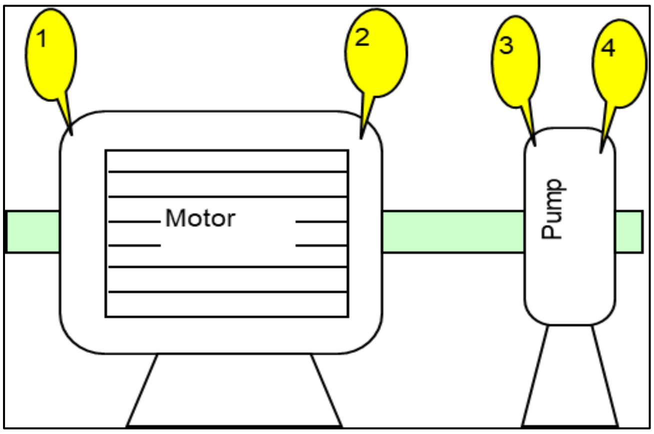

Fig 5 Schematic Diagram of Vibration Measurement Positions.

Figure shows the Schematic diagram of vibration measurement positions of BTRR coolant system.

V. TEST EQUIPMENT

The test was carried out using hand held vibration meter,805 Fluke, Germany. According to the equipment the imbalance severity range (velocity inch/sec peak) is given below:

Table 1 Imbalance Severity Range (Velocity in/sec Peak)

Imbalance Severity Range (Velocity in/sec Peak)	
Very Rough > 0.6	0.1 – 0.2 Good
Rough0.3 – 0.6	0.05 – 0.1 Smooth
0.2–0.3 Slightly Rough	< 0.05 Very Smooth

The Fluke 805 Vibration Meter is a portable diagnostic tool engineered for proactive mechanical maintenance which has been used for the measurement of vibration data.

Fig 6 Fluke 805 Vibration Meter

Its primary function is to quantify bearing condition and overall machine vibration, facilitating the early detection of potential equipment failures. Utilizing a sensor incorporating both vibration and force measurement, the 805 provides quantifiable data for informed maintenance decisions.

VI. RESULTS AND DISCUSSION

This section presents the results obtained from the experimental measurements. The experimental measurements revealed the baseline vibration levels at various locations in the BRR cooling system. The dominant frequencies of vibration were identified, and potential resonance conditions were detected.

Table 2 Peak Velocity (inch/sec) of Vibration Measurement Data of Reactor Coolant Pumps (Position -1)

Equipment Name	Data Accusation Period (Before or After Modification)	Position 1	% of Improvement
SP-1	Before	0.18	33.33
	After	0.12	
SP-2	Before	0.18	44.45
	After	0.1	
PP-1	Before	0.29	68.96
	After	0.09	
PP-2	Before	0.2	65
	After	0.07	

Table 1 presents a comparative analysis of data acquisition periods for various pieces of equipment, both before and after undergoing modification. Specifically, it details the performance at Position 1, measured in an unspecified unit, and quantifies the percentage of improvement achieved through the modification. The data reveals a consistent trend across all listed equipment (SP-1, SP-2, PP-1, and PP-2): the data acquisition period at Position 1 decreases after modification. This reduction translates to a demonstrable percentage of improvement, ranging from 33.33% for SP-1 to 68.96% for PP-1. The table effectively illustrates the positive impact of the modifications on the efficiency of data acquisition, highlighting the potential for enhanced operational performance.

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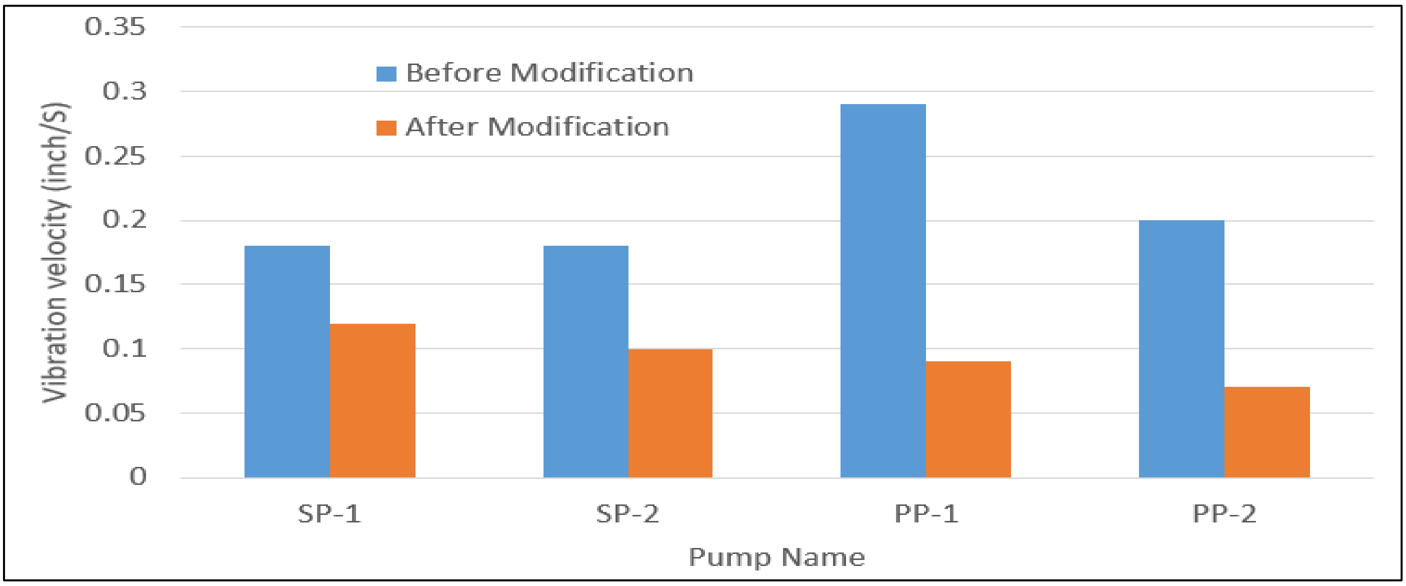

Fig 7 Peak Velocity (inch/sec) of Vibration before and after the Modification

Figure illustrated the improvement of the vibration velocity (inch/s) before and after the modification work done. It shows that the vibration has been reduced dramatically for the primary pump 1 and 2 after the modification work.

Table 3 Peak Velocity (inch/sec) of Vibration Measurement Data of Reactor Coolant Pumps (Position -2)

Equipment Name	Data Accusation Period (Before or After Modification)	Position 2	% of Improvement
SP-1	Before	0.17	41.17
	After	0.1	
SP-2	Before	0.17	23.52
	After	0.13	
PP-1	Before	0.33	75.76
	After	0.08	
PP-2	Before	0.34	70.58
	After	0.1	

The provided table presents a comparative analysis of data for different equipment before and after modification, focusing on "Position 2" measurements. Specifically, the table details the "% of Improvement" in the "Position 2" data after modifications were implemented for equipment SP-1, SP-2, PP-1, and PP-2, demonstrating a quantifiable reduction of vibration. The reductions in "Position 2" values indicate a positive trend following the modifications.

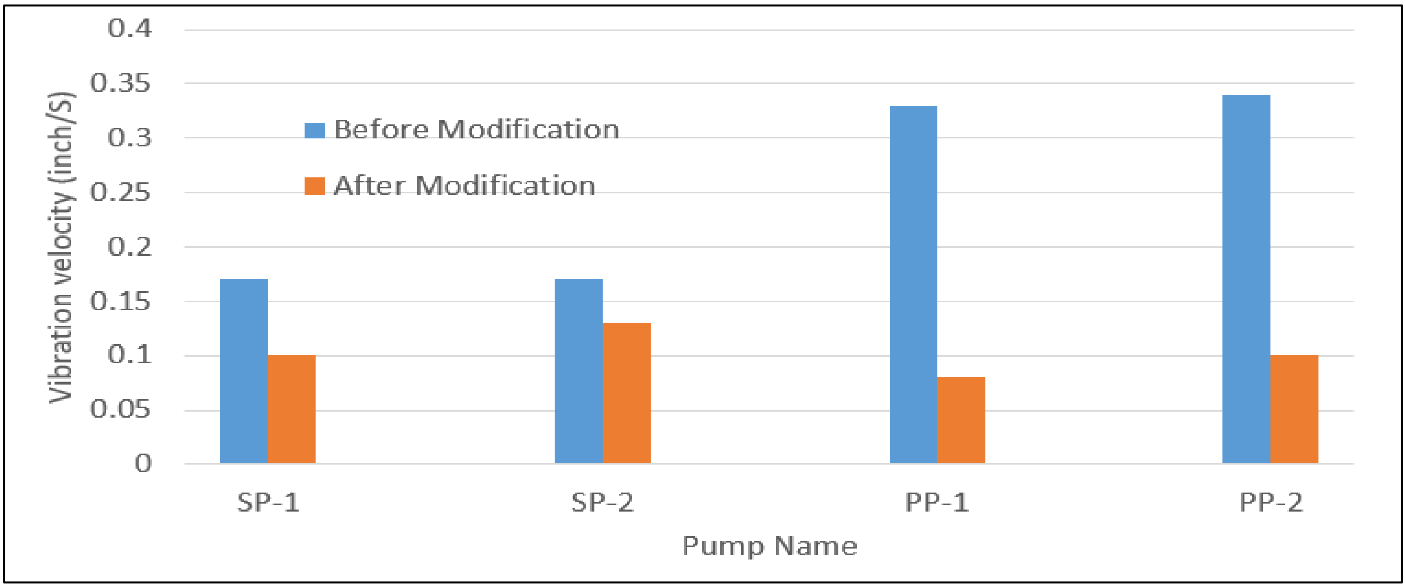

Fig 8 Peak Velocity (inch/sec) of Vibration before and after the Modification

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Figure illustrated the improvement of the vibration velocity (inch/s) before and after the modification work done. It shows that the vibration has been reduced dramatically for the primary pump 1 and 2 after the modification work.

Table 4 Peak Velocity (inch/sec) of Vibration Measurement Data of Reactor Coolant Pumps (position -3)

Equipment Name	Data Accusation Period (Before or After Modification)	Position 3	% of Improvement
SP-1	Before	0.15	20
	After	0.12	
SP-2	Before	0.15	66.67
	After	0.05	
PP-1	Before	0.29	58.62
	After	0.12	
PP-2	Before	0.19	42.10
	After	0.11	

The provided data outlines performance enhancements of several pieces of equipment following modification. For each device (SP-1, SP-2, PP-1, and PP-2), the table presents the data accusation period, categorized as either "Before" or "After" modification. The "Position 3" column quantifies performance metrics pre- and post-modification, while the "% of Improvement" column reflects the percentage of reduction of vibration observed after the implemented modifications. Higher percentages indicate a greater positive impact of the changes on the respective equipment's performance at "Position 3".

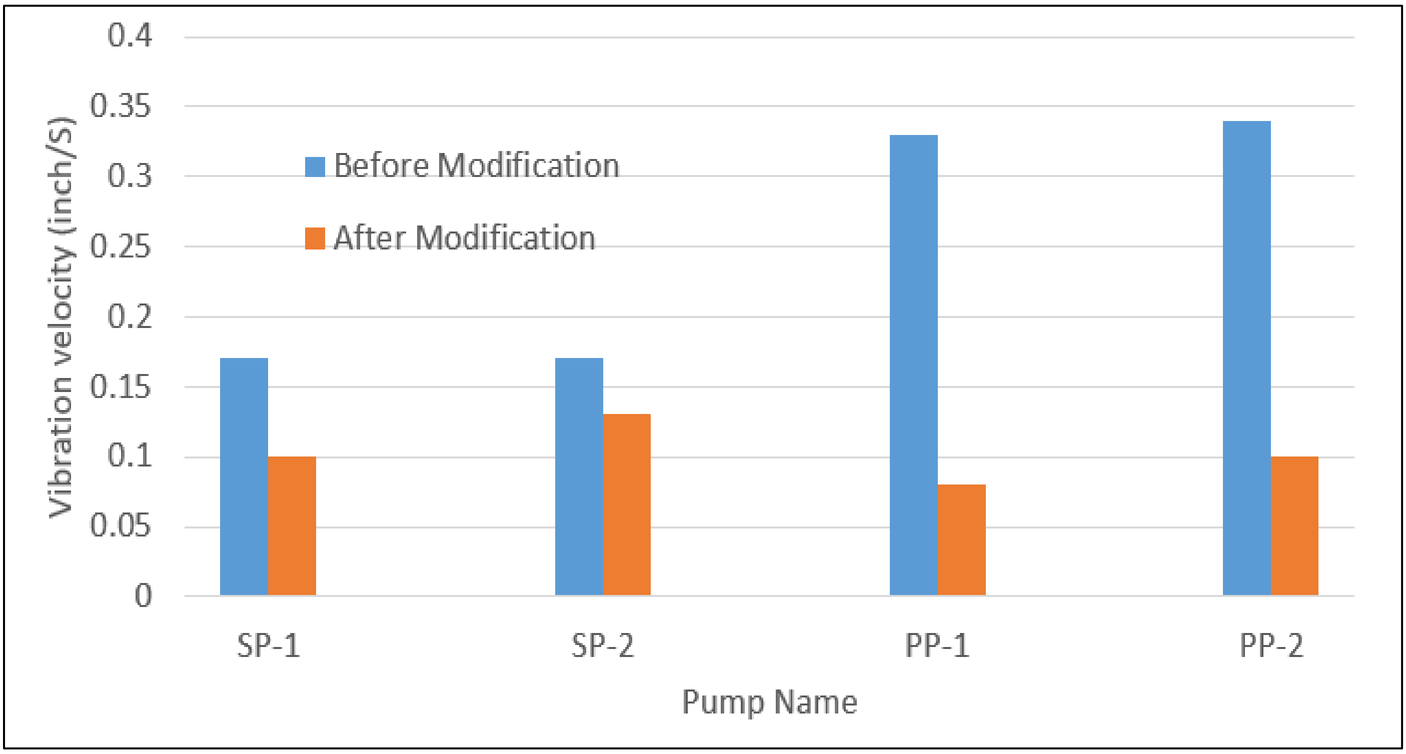

Fig 9 Peak Velocity (inch/sec) of Vibration before and after the Modification

Table 5 Peak Velocity (inch/sec) of Vibration Measurement Data of Reactor Coolant Pumps (Position -4)

Equipment Name	Data Accusation Period (Before or After Modification)	Position 4	% of Improvement
SP-1	Before	0.1	70
	After	0.03	
SP-2	Before	0.1	50
	After	0.05	
PP-1	Before	0.23	78.26
	After	0.05	
PP-2	Before	0.3	70
	After	0.09	

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VII. VIBRATION MITIGATION STRATEGIES

Based on the combined experimental and analytical results, countermeasures were taken to reduce vibration levels and prevent potential damage to the BTRR cooling system.

➢ *Installation of VFD:*

VFDs are electronic devices that adjust the frequency and voltage supplied to electric motors, enabling precise control over motor speed and torque. The incorporation of VFDs within the BTRR facility has significantly optimize various systems, particularly in critical areas such as cooling, pumping, and ventilation. By allowing motors to operate at variable speeds rather than fixed rates, VFDs can reduce energy consumption in cooling systems and auxiliary equipment. VFDs facilitate enhanced control and automation within the reactor facility. Their capacity for real-time monitoring and adjustment enables operators to fine-tune system performance based on specific operational demands. Integration of VFDs at Reactor coolant system leads to reduced mechanical stress on motor and pump components.

Fig 10 VFDs for Primary and Secondary Pumps of BTRR

It became a pivotal aspect of enhancing energy efficiency. These VFDs allows to operate the motor within a desired speed level which results regulated flow rate of coolant. Earlier, flow rate of the coolant was governed by opening of throttle at the discharge side of the pumps which causes tremendous vibration. VFD consents regulated flow and hence reduced the vibration significantly.

➢ *Pump Optimization:*

As a part of pump optimization, a new set of primary and secondary pump motor has been installed at BTRR facility. These pumps are manufactured by siemens company and inclined with the technical specification of previous pump motors. In addition, with that, optimization of the pump operating parameters, such as flow rate control has reduced flow-induced vibration.

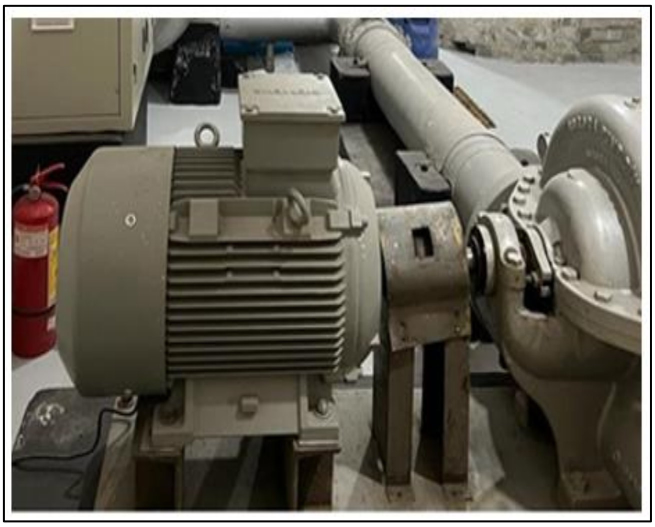

Fig 11 Newly Replaced Primary and Secondary Pump Motor of BTRR

➢ *Structural Modifications:*

Reforms and upgrading works that were implemented in the primary cooling system of the reactor after the decay tank leakage incident such as modification of piping arrangements after the primary pumps, from T shape to Y and providing piping supports has a significant role in vibration reduction.

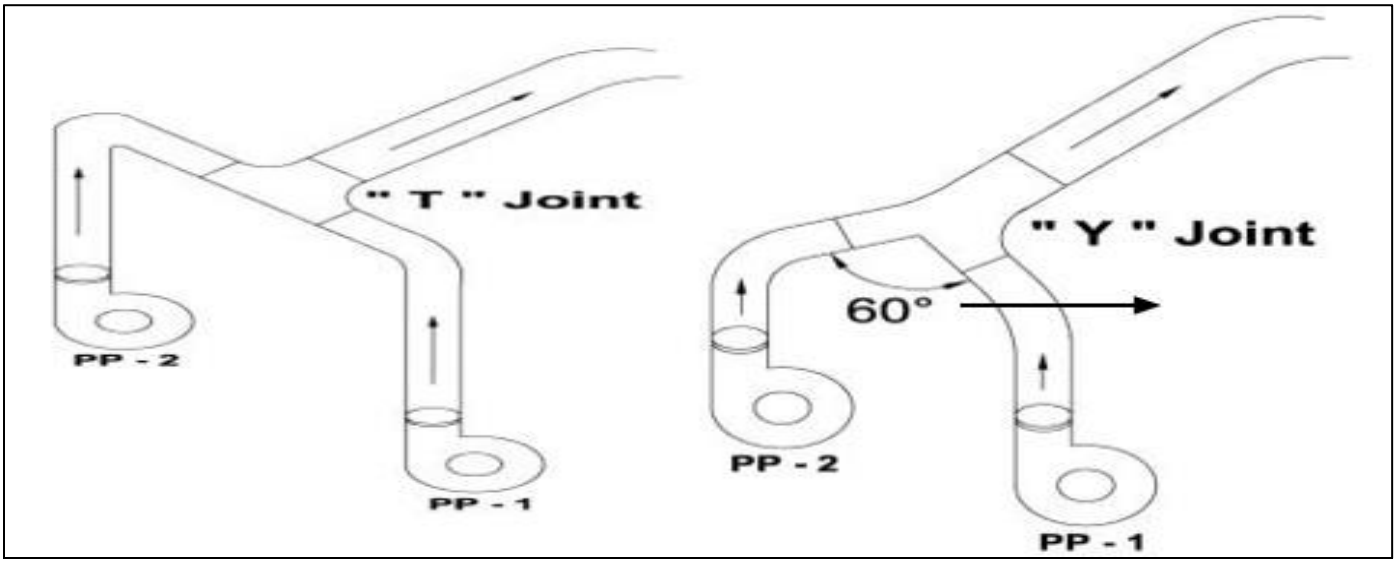

Fig 12 Transformation of Piping Arrangement to Reduce Vibration

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VIII. CONCLUSION

This research paper presented a comprehensive investigation into the vibration behavior of the BTRR cooling system. The study combined experimental measurements and the implementation of vibration mitigation strategies. The results showed that the implemented engineered mitigation strategies were effective in reducing vibration levels and improving the overall reliability and safety of the BTRR cooling system.

➢ *The Key Findings and Conclusions of this Study are:*

- The BTRR cooling system is susceptible to vibration from various sources, including pump-induced vibration and mechanical imbalance.
- Structural modifications, damping enhancements, and pump optimization has significantly reduce vibration levels in the BRR cooling system.

This research provides a valuable framework for improving the vibration performance of the BTRR cooling system and ensuring the safe and reliable operation of BTRR. Further research can focus on exploring advanced vibration mitigation techniques and developing more sophisticated vibration monitoring systems.

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