Proceedings of the
International Conference on Mechanical Engineering 2011
(ICME2011) 18-20 December 2011, Dhaka, Bangladesh

ICME11-AM-047

VIBRATION ANALYSIS OF RENOVATED PRIMARY COOLING SYSTEM OF THE 3 MW TRIGA MARK – II RESEARCH REACTOR

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ABSTRACT

This paper highlights on the vibration assessment between Previous Primary Cooling System (PPCS) and Renovated Primary Cooling System (RPCS) of the 3MW TRIGA Mark-II Research Reactor at AERE, Savar A crack was found in the weld joint of the flange of exit check valve just after Primary Pump-1 resulting in leakage of primary water through it. High vibration also caused number of support failure in common delivery header. The reactor was made operational again at full power after successful replacement of the Primary Cooling System in August 2002. A comparison between the vibration of PPCS and RPCS measurements was done and found good result with each other. Recently, vibration measurements were repeated by the group of engineers of Thermal Hydraulics and Stress Analysis Laboratory (THSAL) of Reactor Physics and Engineering Division (RPED) and Reactor Operation and Maintenance Unit (ROMU) on the same pick points which were measured previously of the Primary Cooling System (PCS). Also comparisons among the previous and recent measurements were done on RPCS and established good corresponding.

Keywords: Vibration, Cooling System, TRIGA Mark – II, Research Reactor and Mechanical Failure.

1. INTRODUCTION

In the PCS of reactor a crack was found in the weld joint of the flange of the exit check valve just after PP1 resulting in leakage of primary water through it. High vibration also caused number of support failure in common delivery header. Investigations were made by vibration measuring equipment. Of these, the decay tank leakage incident of 1997 is considered to be the most significant one. As a result of this incident, reactor operation at full power remained suspended for about 4 years. The reactor was made operational again at full power after successful replacement of the damaged decay tank with cooling system in August 2002; the cooling system was completely replaced. At that time, several modifications of the reactor cooling system along with its associated structures were also implemented. The renovated cooling system was successfully commissioned in June 2002 and through this, it was possible to restore the full power operation of the reactor after a long period of about five years.

The objective of this work is to compare the vibration levels between the PPCS [1] and RPCS. This analysis intends to develop pipe arrangement and various pipe supports of PCS and to reduce vibration for safer operation within the cooling system. Vibration analysis were carried out with previous and present cooling system and presented. Also explained the reason for the new cooling system is minimized critical vibration than previous system. The present work is also to asses the structural integrity through the vibration levels among the previous several years (June 2002 [2], December 2003 and July 2011) measurements done after the installation of the RPCS. This analysis intends to develop the vibration measurements and maintenance criteria of PCS and to control vibration level for safer operation within the cooling system. In the RPCS of reactor; vertical, axial and radial directional vibration data were taken and utmost value of vibration velocities were considered at different measuring points.

2. SYSTEM DESCRIPTION

The function of the PCS is to remove heat from the core in the all operational and accident situations maintaining the core in a safe condition. Heat is extracted by the flow of cooling water through the core either by forced circulation when the reactor is in the high power state (>500 kW) or by the natural circulation when the reactor is in the operational test, shutdown or refueling state. The heat extracted from the core is transferred to the Secondary Cooling System, directly through the heat exchangers of the PCS or indirectly through the reactor and Service Pools Cooling System. Under abnormal Conditions, or if the Reactor Containment Fan Cooler System (RCFCS) is not available, the heat is transferred to the water of the reactor and service pools.

2.1 Reactor Cooling System

The 3 MW_{Th} TRIGA Mark-II research reactor is a water cooled reactor where demineralized water (2 mhos conductivity) is used in closed loop as coolant of the reactor core. This loop is designated as the primary cooling system of the reactor and consists of one decay tank at pump inlet, two centrifugal pumps in parallel having provision of individual operation and one heat exchanger with a small cooling tower. Arrangement of the PPCS is shown in Fig. 1. The system is designed to maintain the flow of demineralized water through the reactor core at a rate of 3,500 gpm so as to remove the 3 MW thermal power being produced in the core from thermal fission. The reactor can be operated in NCCM at power levels up to 500 kW. For operation above 500 kW and up to the full power of 3 MW, forced flow circulation is used through switching of the two pumps delivering 1750 gpm each. The coolant enters the reactor tank through a 25.4 cm line which penetrates the side of the tank near the top of the pool. The coolant is drawn by pump suction through the core upper shroud, down through the reactor core and into the core lower plenum. From the lower plenum, the coolant enters a 30.5 cm diameter pipe and travels in a shielded trench to the gamma emitting N-16 decay tank and then to the suction side of the primary pumps. Two pumps operating in parallel circulate the coolant through the heat exchanger and back to the reactor tank. System flow is adjusted to 3,500 gpm by using the 20.5 cm manually operated butterfly valves situated in the pump discharge lines. Moreover there are two valves at the discharge lines of the primary pumps and each valve is kept open by same amount (40º position) so that both the pumps equally share the coolant flow and hence pressure loss in each of the pump circuits. There are check valves (exi-checks) at the discharge of the pumps to prevent back flow of water. The failure of flange weld had occurred in one of these valves in 1990 after a continuous operation of pumps for 54 hours.

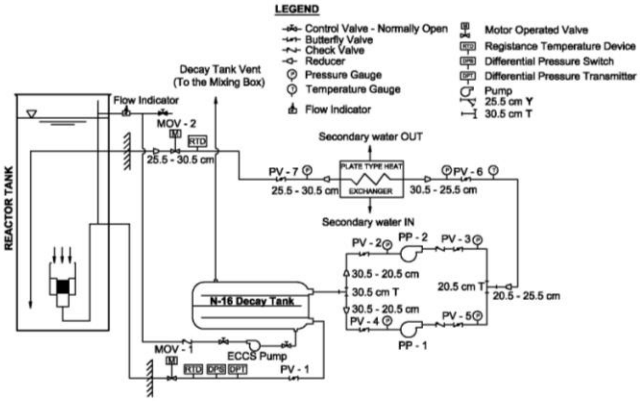

Fig 1. Schematic of PPCS and Instrumentation Diagram

Arrangement of the RPCS is shown in Fig. 2. The steady state mode of operation of the reactor is performed under two cooling modes; Natural Convection Cooling Mode (NCCM) and Forced Convection Cooling Mode (FCCM). The NCCM is used to operate the reactor up to power level of 500 kW. During the NCCM of operation, generated heat in the reactor core is removed by the tank water through natural convection cooling mechanism. Meanwhile, for the operation of the reactor from 500 kW to 3 MW power level, FCCM is used. Heat generation during this mode of operation is dissipated into the atmosphere through a cooling system consisting of primary and secondary cooling circuits.

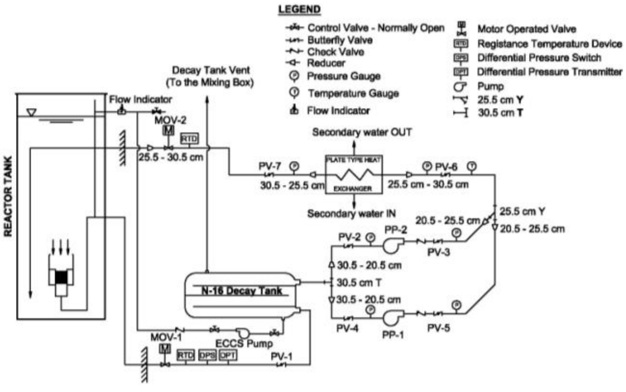

Fig 2. Schematic of RPCS and Instrumentation Diagram

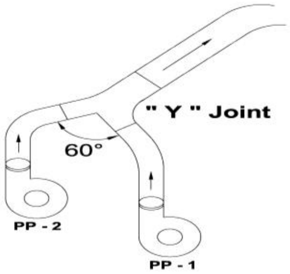

Fig 3. RPCS “ Y ” Joint Connection

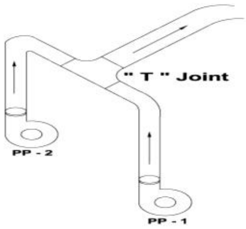

Fig 4. PPCS “ T ” Joint Connection

3. NATURE OF FAILURE AND BACKGROUND OF PPCS

A crack was developed in the welding joint of the exi-check valve of the PCS on 2^{nd} September 1990. The crack developed primarily due to faulty primary pump foundation and the pipe support system. The design of the system also contributed partly to the excessive vibrations. The check valve is located in between the pump discharge and adjustable butterfly valve as shown in Fig. 5.

3.1 Problem with the Reactor Cooling System

3.1.1 Exi-Check Valve Incident

A crack, having a circumferential length of about 25 cm, was found to be developed in the welding joint of the exi-check valve of the PCS on 4th September 1990. The failure was thoroughly studied. Upon investigation, it was found that the crack had been developed primarily due to excessive vibration arising because of faulty primary pump foundation and the pipe support system. The layout design of the primary piping system also contributed partly to the excessive vibrations [3].

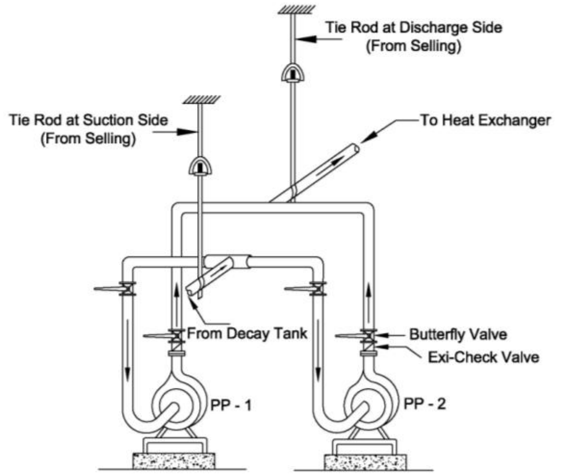

Fig 5. Location of Exi-check Valve in PPCS

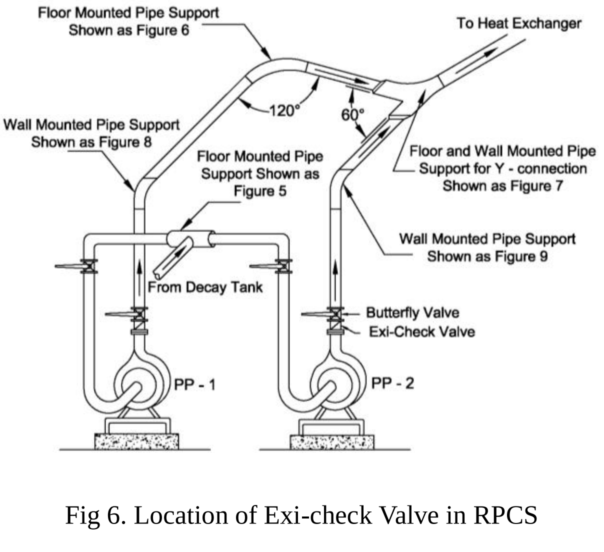

Fig 6. Location of Exi-check Valve in RPCS

3.1.2 Problem with the Vibration in the Discharge Line of the Primary Pump

It was found that vibration induced stress in the primary pipes was one of the reasons for this failure. Design defects such as pipe supports, layout, couplings spacers and hubs; misalignment of pump and motor, defective motor bearings, static imbalance of pump impeller and undesirable throttling of discharge valves of the pumps were identified as some of the possible reasons leading to the fault. The exi-check valve was duly repaired and reinstalled. Pipe supports and pump foundations were modified so as to reduce stress and vibration by incorporating some additional valves, replacing a "T" joint with a modified "Y" joint shown in Fig. 2. Impeller and shaft of the primary pumps were also balanced statically to reduce vibration.

3.1.3 Problem with the Primary and Secondary Pumps

Electrical phase changed by REB, local electricity supply authority, the impeller of PCS pumps were found to get stack with volute casing due to reverse rotation. This caused the snap ring (retainer ring) to be damaged. ROMU`s Mechanical Maintenance Group replaced the damaged snap ring with a new one. Bearings of the pumps & motors of the primary and secondary cooling pump-motor set replaced by new ones [4].

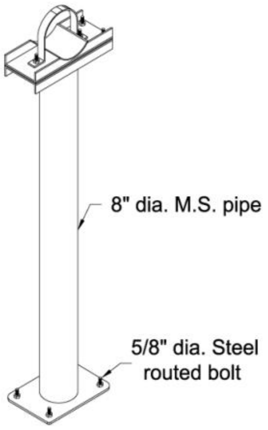

Fig 7. Pipe support at the suction side of Primary Pump

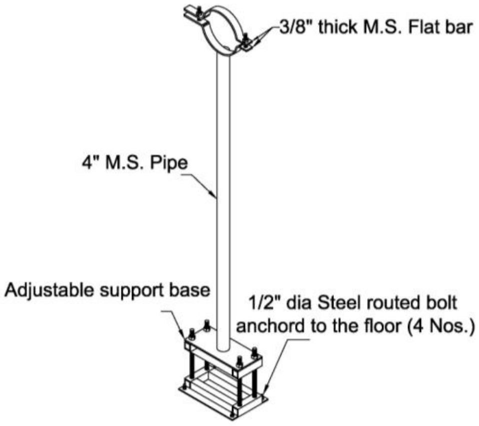

Fig 8. Adjustable Pipe support between PP1 discharge line and Y-connection

4. RENOVATION OF THE PCS

4.1 Reactor Primary Cooling System Reforms

Reforms and upgrading works that were implemented in the PCS of the reactor after the decay tank leakage incident of 1997 are described in the following sections.

The purpose of the reform and upgrading works was to ensure safe and reliable operation of the reactor cooling system with improved heat transfer performance [5].

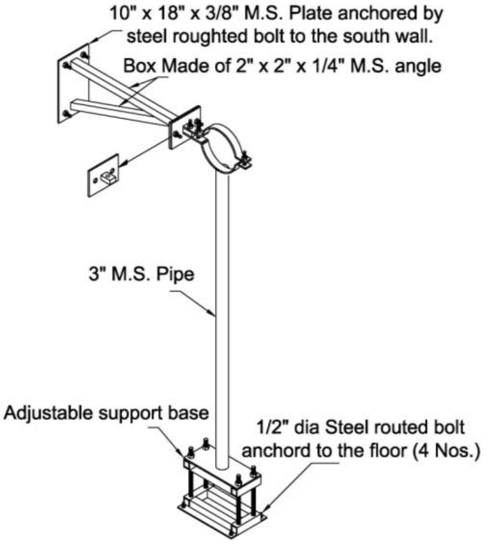

Fig 9. Pipe support of RPCS in Y-connection

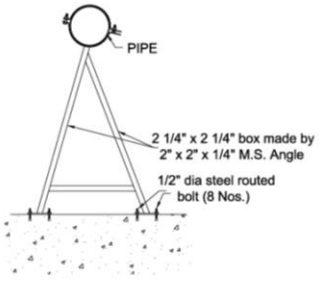

Fig 10. Pipe support at the discharge line of PP1 from the East wall

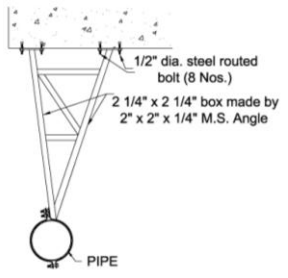

Fig 11. Pipe support at the discharge line of the PP2 from the West wall

4.2 Reform of the PCS Piping Arrangements

A modified Y-connection (Fig. 3) was introduced in place of the T-connection (Fig. 4) at the discharge side of the two 50-hp pumps, which are operated simultaneously to get the desired primary flow rate of 13,230 liters/minute (3,500 US gallons/minute). It may be mentioned that a "T" connection in the discharge line of any pumps gives rise to "cavitations" like noise depending upon the degree of turbulence. The "Y" connection in the discharge resolved the matter to a great extent.

A butterfly valve was installed at the inlet of the decay tank. Two 25.4 cm (10 in.) butterfly valves were installed in primary piping adjacent to the inlet and the outlet of the plate type heat exchanger shown in Fig. 6. Design of the secondary cooling system piping arrangement at the inlet of the heat exchanger was changed so as to facilitate the maintenance of the Y-strainers [6].

4.3 Reform of Pipe Supports

Necessary pipe supports were provided at different locations of the primary and secondary cooling loops in order to reduce the vibration of the piping to a minimum level. Three types of mild steel (M.S.) pipe supports were used for this purpose that include adjustable floor mounted type (Fig 7 and 8), wall mounted type (Fig 10 and 11). In addition to these, a few supports, which were connected simultaneously to the floor and the wall, were also installed (Fig 9). The above were essentially conventional steps taken to mitigate piping vibration. In most cases the inherent vibrations of the pump act as the forcing function. The pipe supports were placed at places of maximum amplitude.

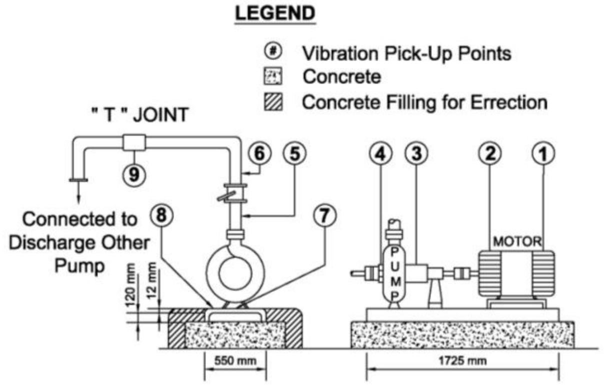

Fig 12. PPCS Pick- up Points for Vibration Measurement

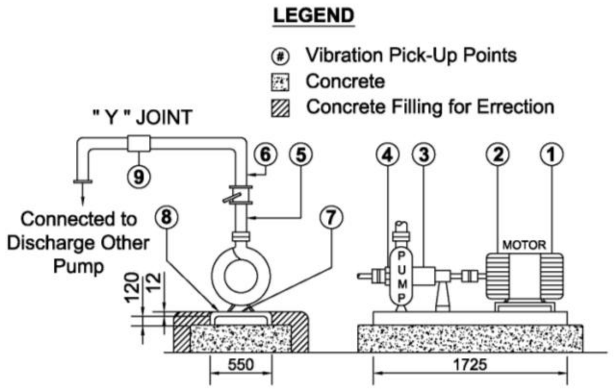

Fig 13. RPCS Pick-up Points for Vibration Measurement

5. VIBRATION DATA COLLECTION AND DATA ANALYSIS FOR BOTH PPCS AND RPCS

To collect vibration data for analysis on the selected pick-points shown in Fig. 12 for PPCS and Fig. 13 for RPCS, measurements were taken by THSAL of RPED & ROMU authority. The measurements were repeated after the rectification exercise on the selected pick points to record each time in order to judge better condition after the rectification work. Study based on measurements showed that the vibration on those pick points showed improvement structurally reducing vibration level to a lower value for RPCS.

Vibration of auxiliary plant has traditionally been measured in units of velocity (mm/s), which gives an indication of the condition of the plant relatively insensitive to speed. Recently, vibration measurement was repeated on the same pick points as before and was studied for analysis to justify the operational safety of the primary piping system. The purpose of this is to validate our measuring procedure so that we establish routine checking of the primary piping system of the research reactor for the purpose of maintaining the operational safety of the reactor in its life time. Vibration monitoring is complex and many parameters must be observed simultaneously. Vibration monitoring has been done with more efficiency, safety and confidence by the authors. In the RPCS of reactor; vertical, axial and radial directional vibration data were taken and utmost value of vibration velocities were considered at different measuring points shown as Fig. 13.

6. TEST EQUIPMENT

The test was carried out using TK-83 - Hand Held Balance Master and TK- velocity Transducer (Bently Nevada, USA). Velocity Scale Factor was 500 mV/in/s.

According to the equipment the imbalance severity range (velocity mm/sec peak) is given below:

Very Rough: > 15.24
Rough: 7.62 – 15.24
Slightly Rough: 5.08 – 7.62
Average: 2.54 – 5.08
Smooth: 1.27 – 2.54
Very Smooth: > 1.27

7. DISCUSSION

The test results are shown in the Figs. 14 and 15 between PPCS and RPCS results for comparison. In general, the measured data of vibration velocity are better in RPCS than PPCS for both PP1 and PP2. The renovation work was performed to sustain safe and reliable operation of the reactor because of lower vibration levels occur in RPCS than PPCS. After satisfactory installation of the plate type heat exchanger and Y-connection some of the parameters of the secondary systems were found to improve. Figs. 14 and 15 show the improvements.

From Figs. 14 and 15, it is observed that after installation of Y – connection (Fig. 3) instead of T – connection (Fig. 4) and appropriate pipe supports (from figs. 7 to 11), the vibration level of the primary pumps & motors have minimized significantly and thus ensured safer operation of the reactor cooling system. It is remarkable that the vibration level at point 5 and 6 (Previous Crack Point) have minimized expressively because of the appropriate renovation of pipe support at various points (Fig. 6) in RPCS. Besides these, the other modification work that were implemented in the reactor cooling system (ECCS, decay tank, etc.) have also enhanced the overall safety of the reactor.

The test results are shown in the Figs. 16 & 17 among vibration velocities measured in different year in RPCS results for comparison. According to the Imbalance Severity Range (Velocity mm/sec) Slightly Rough vibration values were observed in the motor side and Average vibration values were observed in the pump side, indicating some problem in the motor bearings. Consequently, the bearing of this motor is frequently damaged. The measured vibration levels along the pump and motor axis (locations 1 to 4 in the Fig. 13) are relatively average and uniform, therefore, this set up is considered to be satisfactory for the continued operation.

The vibration values at position 6 of the both discharge pipes are in Rough according to the Imbalance Severity Range (Velocity mm/sec). This indicates that the vibration at position 5 is not due to the vibration from the pump-motor assembly but alternating thrust and pressure waves occurring at the “Y” -joint.

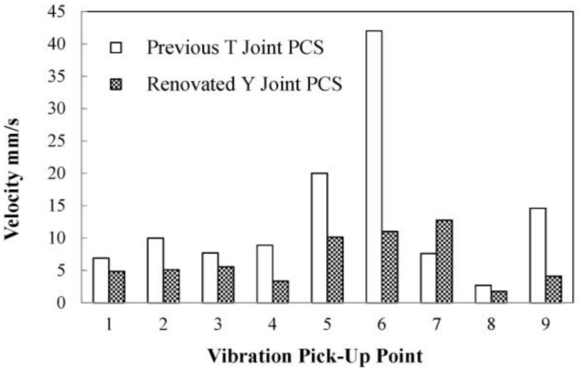

Fig 14. Comparison of Vibration Velocities between PPCS and RPCS for PP1 [1, 2]

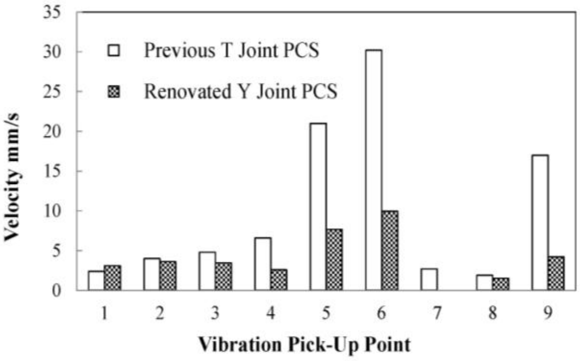

Fig 15. Comparison of Vibration Velocities between PPCS and RPCS for PP2 [1, 2]

8. CONCLUSION

The reactor has so far been operated safely for various peaceful applications in the field of nuclear science and technology in the country. However, a few incidents took place at the facility which could be managed satisfactorily. The modification, rectification and upgrading works of the facility were carried out locally. The structural rigidity of the RPCS is better than the PPCS because of low vibration levels are occurring in RPCS. Based on this analysis it is concluded that RPCS is more reliable than that of PPCS for safe reactor operation.

It is also concluded that the structural integrity of

RPCS decreases with time from the vibration analysis results. Vibration analysis outcome establishes that we developed the local expertise in analyzing the vibration in the reactor primary piping system so as to evaluate the operation safety of the reactor in its total life time.

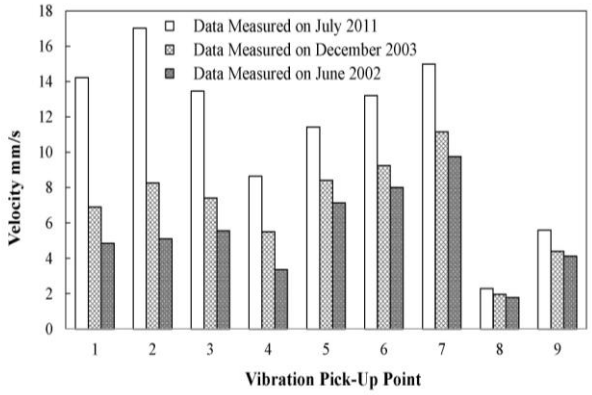

Fig 16. Comparisons of Vibration Velocities for RPCS for PP1

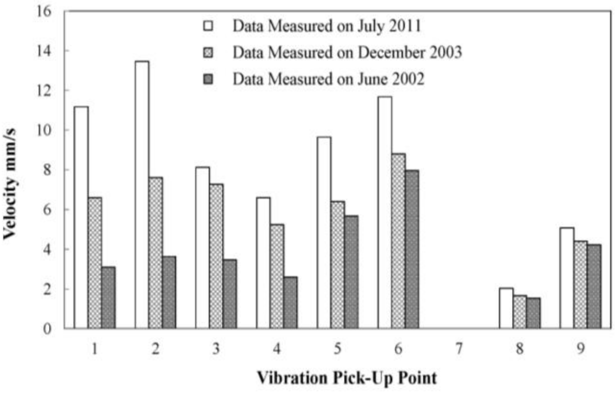

Fig 17. Comparisons of Vibration Velocities for RPCS for PP2

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10. NOMENCLATURE

Symbol	Meaning
PPCS	Previous Primary Cooling System
RPCS	Renovated Primary Cooling System
AERE	Atomic Energy Research Establishment
PP1	Primary Pimp 1
PP2	Primary Pimp 2
RPED	Reactor Physics and Engineering Division
ROMU	Reactor Operation and Maintenance Unit
PCS	Primary Cooling System
RCFCS	Reactor Containment Fan Cooler System
NCCM	Natural Convection Cooling Mode
FCCM	Forced Convection Cooling Mode
REB	Rural Electrification Board
ECCS	Emergency Core Cooling System

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