WATER INDUCED VIBRATION IN THE NSRRC

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Abstract

Water flow related vibrations were found on the spectrum of electron beam position monitor in the NSRRC. They were associated with the vibrations of quadrupole magnets. One major vibration source was from a pump in the cooling water system. Most amount of vibration coupled through water pipe and water flow and propagated to the magnets. A small water flow station was set up to study the effect about coupling, propagating and excitation. Some damping schemes tested in the ring to improve the vibration are also included.

INTRODUCTION

From the spectrum of electron beam position monitor in the NSRRC we found a water flow related signal at 29 Hz being a major peak. This vibration signal was also found in the quadrupole magnets, water pipes and ground in the ring. To get high stable beam the vibration level would be as low as possible. Water-cooling was indispensable for some magnets and beamline components. It acted as a excitation source when the flow reached a turbulence region [1,2]. Flow vibration related phenomena such as vortex, turbulence effect [3], source-propagating and substructure coupling would contribute to the vibration of components. In this study, we will present the status of cooling water in the ring, improvement in the ring and some tests in a small flow station.

Status of Water Vibration in the Storage Ring

Cooling water of ring components was supplied from the utility building that was about 100 meters away from the storage ring. There were individual supplying subsystems for vacuum, magnet, beamlines and etc. Centrifugal chillers were used to cool down the returned water from subsystems. Each chiller was water cooled by its cooling water pump and cooling tower assembly.

The source of 29 Hz was identified from the cooling water pump of the chiller. It disappeared only when the cooling water pump of chiller was shut down, but still appeared even the circulating water pump of the subsystem was turned off. The measurement of ground vibration at 29 Hz in the ring and experimental floor was shown in the Table 1. We can see the vibration signal did not follow the simple decaying equation. The amplitude was higher in the water pipe of the ring. It suggested that the propagating route was not through homogeneous medium only from ground, one major contribution might be propagating from the pipe. For each subsystem the main pipe started from utility center to storage ring and distributed into 12 branches (medium pipe) along circumference of ring and then to manifold panel. Pressure drop from utility center to manifold is about 0.5 Kg/cm^2. The pressure was supposed to drop at valves and joints of branches. The Reynold's number in the main pipe was in the order of 10^5, in the vacuum chamber of 13000 and in the quadrupole magnet of 3500. All this Reynold's numbers were far beyond the turbulence flow threshold, Reynold's number 2000.

Table 1: Vibration propagating of pump frequency

	Location	Distance from source (M)	Acceleration (m/sec^2)
1	Utility Chiller stand	0	1exp -2
2	Ground near chiller	2	4exp-3
3	Ground of 1st utility building	20	1exp-3
4	Ground of SR building near utility	40	3exp-4
5	Ground near control room	60	3exp-4
6	Ground of X-ray BL (Near middle)	60	2exp-3
7	Ground of X-ray BL(near SR)	65	1exp-3
8	Ground of BL01	95	5exp-4
9	Ground of BL 04	110	2exp-4
10	Ground of BL08	120	2exp-4
11	Ground of Entrance	130	3exp-4
12	DIW pipe R4 trench	100	4exp-3
13	Ground of R4	90	1exp-4
14	R4 Quad Magnet	90	3exp-4

IMPROVEMENT IN THE FLOW VIBRATION OF THE STORAGE RING

In general, vibration in the specific components was the compound effect of vibration source, propagating route and structure excitation mode. In the normal operation machine it was not easy to change the components design, reducing the source vibration is possible but not so quickly, so we decided to reduce the propagating route. The main pipe and medium pipe were all metal. Part of pipe from manifold to magnet was rubber or PE pipe for the electricity isolation. For vacuum system the pipes were all metal. Because chamber was mounted on the magnet girder, so vibration propagating along the chamber would also influence the magnets. Rubber pipe was expected to be better than metal pipe for reducing the vibration propagating. In the 2005 spring shutdown, we changed part of the medium pipe of chamber flow system from stainless steel to rubber hose in each branch. They were about 10 meters long for each branch. In addition, in the main pipe we added some metal bellows to reduce the vibration propagating.

Table 2 shows the improvement of vibration in the ground, magnet and BPM reading after pipes changing. The data were the average of 6 days normal operation, which were recorded with an on-line monitoring system. We can see the amplitudes of water cooling pump at 29 Hz reduced about 5 times on magnet and 2 times better in the BPM reading. The major natural frequency of girder around 15 Hz was not significantly improved by this pipe changing. Comparing the frequency response function of magnet assembly as shown in the Figure 1, we can see there was a twist mode of girder around 33 Hz, so the 29 Hz excitation was also in the high magnification region. In alternate solution it may be possible to reduce the source vibration of chillers. In normal operation two chillers offered the total cooling capacity for the total ring system. Yet there was only one big cooling pump for each cooler. If more small pumps could replace the one big pump the vibration would be less. Added some commercial damping material in critical parts would also be helpful

Table 2: Improvement of ring vibration at pump driven frequency by changing part of medium pipe from stainless to rubber.

	Ring Ground	R3BPM5X	R3BPM5Y	R5Q5 ver	R6Q5 ver
Before	3.7-20nm	0.22um	0.34um	27nm	24nm
After	3-12nm	0.1um	0.14um	3.3nm	4.5nm

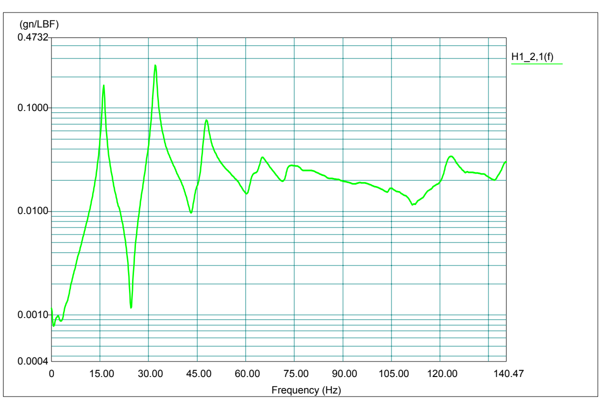

Figure 1: Frequency response function of magnet girder.

WATER FLOW TEST STATION

To understand the coupling effect of flow between chamber and magnet, we set up a spare magnet girder similar to ring version and installed two quadrupole magnets and one vacuum chamber on the girder as shown in Figure 2. One magnet weighed about 400 Kg, the chamber was about 30 Kg. A small water supply system with pressure-regulated type similar to our ring water system was also prepared. Local flow adjusting valves and flow meters were installed. Nominal flow rate for one quadrupole magnet is 2.4 liter per minute; for vacuum chamber is 5 liter per minute. Different configurations of piping to magnet and chamber were arranged in order to meet our test purpose.

The vibration was measured by LDS spectrum analyzer, sensor was accelerometer PCB 393B12. The setting was 800 lines, span 142 Hz, 20 times linear average. Vibration RMS displacement was integrated in power spectrum density (meter^2/Hz) from 10 Hz to 100 Hz and took square root. The calculation was offered by the software of LDS and confirmed by the function generator. The variation of measurements was within 10%. It should be noted that the vibration of magnet in the test area was about 2 to 3 times higher than that of in the ring. It maybe related to the different configuration of chamber and a little higher floor vibration.

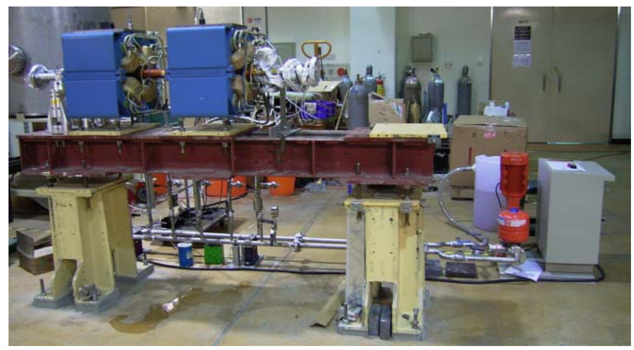

Figure 2: The photo of water flow station.

RESULTS AND DISCUSSION

a. Flow-Induced Vibration on the Magnet

Figure 3 and 4 shows the PSD spectrum of the magnet in horizontal and vertical direction with pump on and off condition. We can find the PSD spectrum was shifted higher after water flowed. Additional peak such as 14 Hz and others were excited. The integrated displacement was in the item 1 and 2 of Table 3. The net increase vibration on quadrupole magnet was about 100nm in horizontal and 40nm in vertical direction.

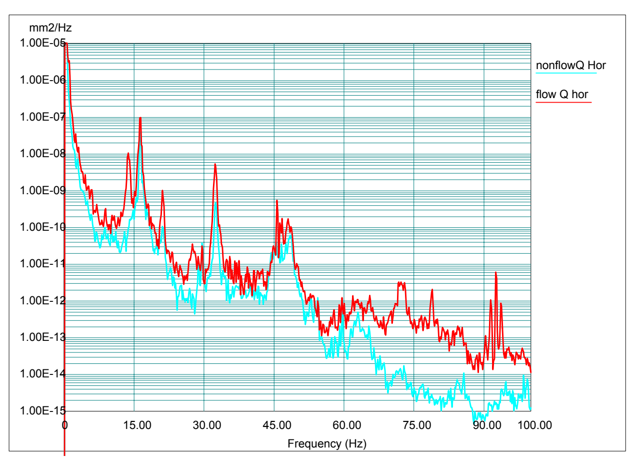

Figure 3. Compare the water flow and no flow on the Q magnet vibration in the horizontal direction.

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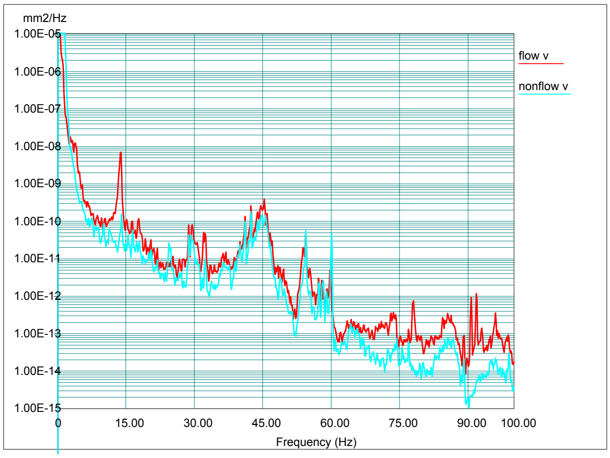

Figure 4. Compare the water flow and no flow on the Q magnet vibration in the vertical direction.

b. Vibration Coupling Between Magnet and Chamber.

Next we compare the coupling of the vibration between the magnet and chamber. We let the chamber with no pipe connecting to the water system. After the pump turned on only magnets water flowed. It would eliminate the influence the chamber vibration on the magnet. We found that the 14 Hz peak disappeared. It was clear to know the new peak 14 Hz was associated with the chamber vibration. When we compare the item 2 and 3 of Table 3, the net increase of chamber- induced vibration was about 50 nm in horizontal and 30nm in vertical direction.

Next case, we let magnet A water flow and magnet B have no connecting pipe. We found magnet A and B have nearly the same major vibration response despite only magnet A water flow. Another case we change the pipe of chamber input from metal bellows to PU tube with the same length. We found the vibration amplitude was 4 times higher.

From the above test, we know the water flow in the high Reynold's number will excite the natural frequency of all substructures and then propagate out. If these substructures have common girder the vibration will superpose together. Therefore, from the consideration of vibration, to decouple the chamber with the magnet girder would be a reasonable approach.

c. Valve Effect

In the item 4 of Table 3, we closed the valve of chamber flow, then only magnet water flowed. We found the vibration amplitude was not lowered when the water flow of chamber was stopped. It seemed momentum of water flow impacted on the valve and transmitted along the pipe to the magnet. Because there was no flow in the valve close condition, the transmission of vibration would be mostly along pipe material rather than from static water. Water momentum impact struck on the stopped valve was like a hammer. In this case changed the pipe material to higher damping rubber would be helpful. In the partly open condition of valve, another source of vibration called the vortex shedding may occur. When the flow through an abrupt changed orifice the water pressure will change. The pressure drop across the valve would cause the bubble formation and two phases flow would induce flow vibration. In this situation the water velocity and pressure were related parameters. Therefore, in the neighbourhood of valves some damping device like the rubber surge suppressor or a rubber pipe may be helpful for the vibration damping.

Table 3: Integrated RMS displacement from 10 to 100 Hz of different test conditions on a quadrupole magnet.

Item	Condition	Q magnet horizontal	Q magnet vertical
1	Pump off Magnet, chamber water pipe normal link	115 nm	29 nm
2	Pump on Magnet, chamber water flow	222	71
3	Pump on Magnet water flow, chamber pipe decouple	177	40
4	Pump on Magnet water flow, chamber close valve	225	73
5	Pump off Magnet pipe link, chamber pipe decouple	170	36

SUMMARY

From the above tests in the storage ring and flow station, some conclusions are given below.

1. When the normal flow condition of magnet and chamber reached a turbulence region, it behaved as a random vibration source to excite the natural frequency of all components.
2. Flow-induced vibration in the chamber and magnets are easy to cross talk if they sit on the same girder.
3. Valve is a potential vibration source in the partial-opening and closed condition.
4. A damping scheme by using rubber pipe to reduce the vibration transmission along pipe had positive result in the storage ring.

REFERENCES

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