Vibration Assessment Method and Engineering Applications to Small Bore Piping in Nuclear Power Plant

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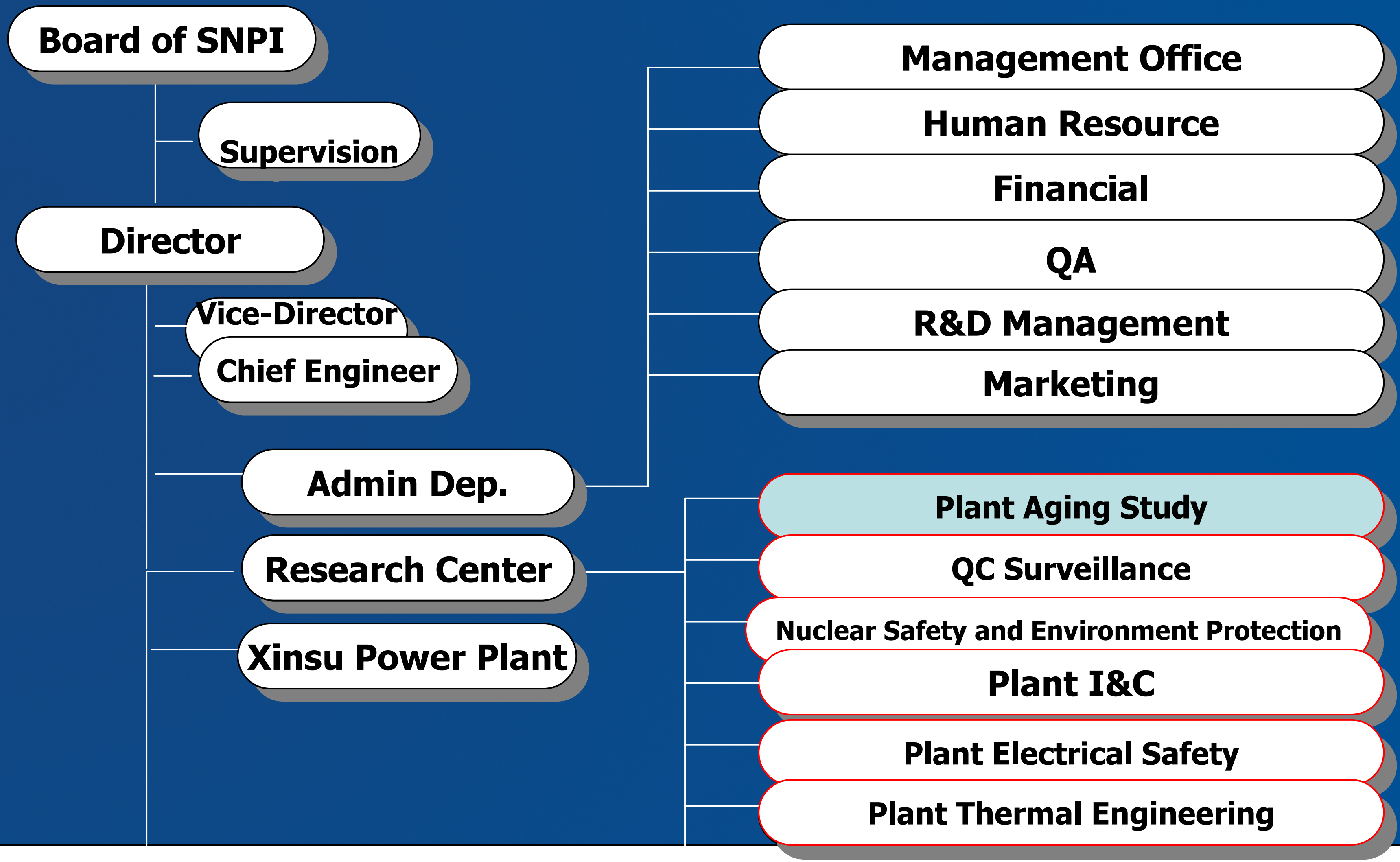
Introduction of SNPI

Structure of SNPI



Major Research Fields

Main Research Fields

- Aging and Life Study of Plant Component
- Equipment Manufacturing QC Surveillance
- Nuclear Safety Review and Surveillance
- Environment Impact Assessment
- NPP Site Selection and Evaluation
- Non-Destructive Evaluation(PSI/ISI)
- Plant I&C Engineering and Development
- Plant Thermal Engineering and Chemistry
- Plant Welding and Maintenance

Laboratory (Metallic Aging)

Aging Laboratory

- Raw Material Performance
- Material Fatigue Performance
- Material Corrosion Performance
- Material Erosion Performance

↔ **Examination Facility**

Fatigue Crack Growth Measurement System

Plant Ageing and Life Study

- Metallic equipments, for example
  - RPV
  - SG
  - Primary loop pump
  - Pressurizer
  - RVI
  - ……
- Metallic pipes, for example
  - Primary loop pipe
  - Auxiliary pipe of Primary loop pipe
  - Main feedwater pipe
  - Small bore line
  - ……

- Aging mechanisms
  - Thermal Aging Embrittlement
  - Thermal Fatigue
  - Vibratory Fatigue
  - FAC (Flow Accelerated Corrosion)
  - Irradiation Embrittlement
  - SCC
  - ……

Piping Vibration Assessment Method and Engineering Applications to Small Bore Piping in Nuclear Power Plant

Project Background

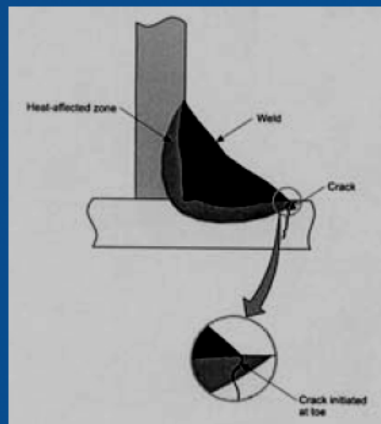
- Vibratory Fatigue Phenomena：
  - 1991, leak from two small branch tube socket welds in unit 2 of Safety Injection system in Belleville Nuclear Power Plant, which leads to concern of small bore pipe vibratory fatigue.
  - Small bore pipe vibratory fatigue cracks also found in other NPPs in the world.
  - Since 1993, more than 11 vibratory fatigue cracks were found in Daya Bay and LingAo Nuclear Power Plants.

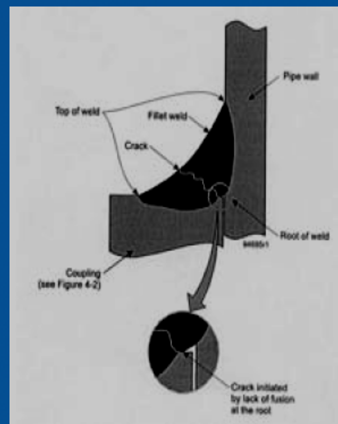
Project Background

- Period safety review requirement
  - In the first 10 years safety review of Daya Bay Nuclea r Power Plant, vibration assessment for small bore pip es was required as one of the 'special project'.
  - 2004, vibration assessment for NI small bore pipes w as performed.
  - 2005, SNPI began the vibration assessment for CI sm all bore pipes of Daya Bay, unit 1. (Finished)
  - 2006~2007, vibration assessment for CI small bore pi pes of Daya Bay, unit 2 were finished.

Cause of small bore pipe vibratory fatigue

- ❑ **Failure mode---- Low stress , high cycle fatigue.**
- ❑ **Excitation mode----**
  - ❍ Pressure pulsation, cavitation, flashing caused by pump ;
  - ❍ Socket welds----the geometry size, discontinuity , and residual stress;
  - ❍ Design error---Inappropriate supports lead to resonant of piping system;





Assessment criterion

- Vibration monitoring and assessment criterion：
  - ASME OM-S/G part3-2000
    - VMG3：Evaluated by visual inspection
    - VMG2： Evaluated by peak velocity and displacement
    - VMG1： Evaluated by vibratory stress
  - EDF method（Sébastien Caillaud, Didier Briand, 2003）
    - Effective velocity assessment method

Peak Velocity criterion

- Peak velocity (Vp) assessment method－ASME OM part 3

$$V_{allow} = \frac{\alpha C_1 C_4}{C_3 C_5} \frac{0.8\sigma_{al}}{C_2 K_2}$$

- Screening value: Vps=12.7mm/s
- If Vt>12.7mm/s, the allowable peak velocity Vpa shou ld be calculated using the above equation.
- If Vt>Vpa, the vibration stress should be tested and c ompared with the allowable stress.
- Monitoring program or modification measures been pe rformed.

Effective velocity criterion

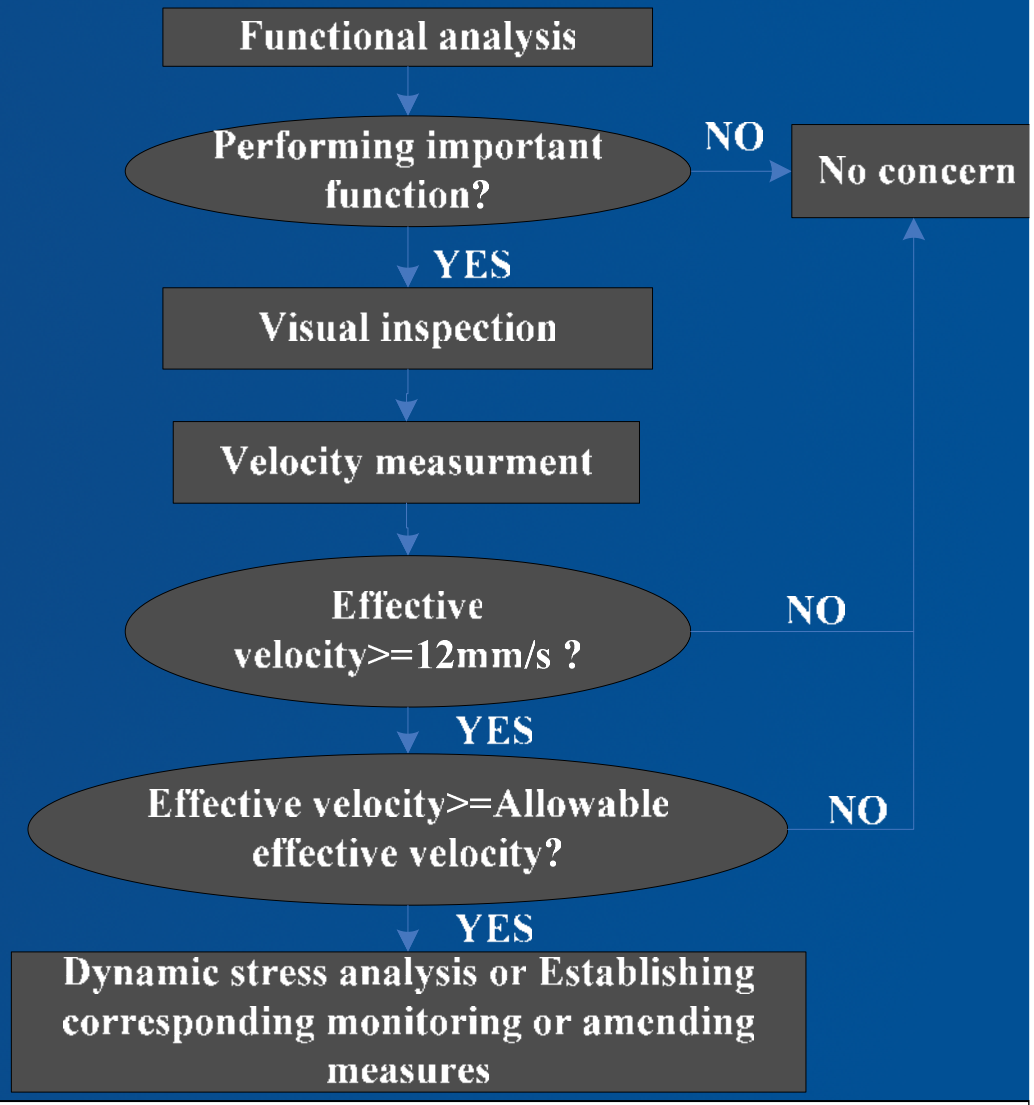
- Effective velocity (Ve) assessment method－EDF

$$V_{\text{allow}}^{\text{rms}} = \frac{C_1 C_4}{C_0 C_3} \times \frac{\lambda}{C_2 K_2} \times 0.8 S_A (mm/s)$$

- Screening value: Ves=12mm/s
- If Vt>12mm/s, the allowable effective velocity Vea shou ld be calculated using the above equation.
- If Vt>Vea, the vibration stress should be tested and co mpared with the allowable stress.
- Monitoring programme or modification measures been p erformed.

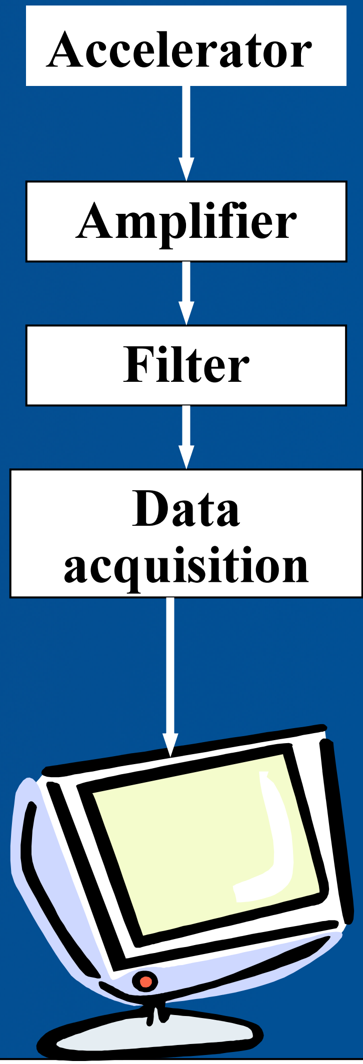
Application of velocity assessment method

- Assessment programme:
  →ASME OM Part 3
- Assessment criteria:
  → Effective velocity criteria
- Target:
  → Daya Bay Nuclear Power Plant, CI of unit 1
- Condition:
  → Performed during the operating time.
- Material:
  → Carbon steel; Stainless steel

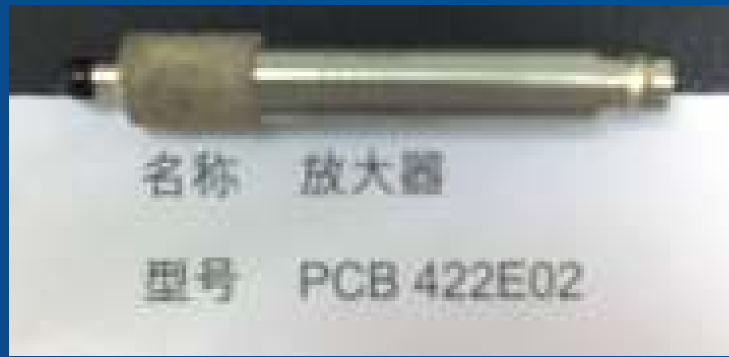


Application of velocity assessment method

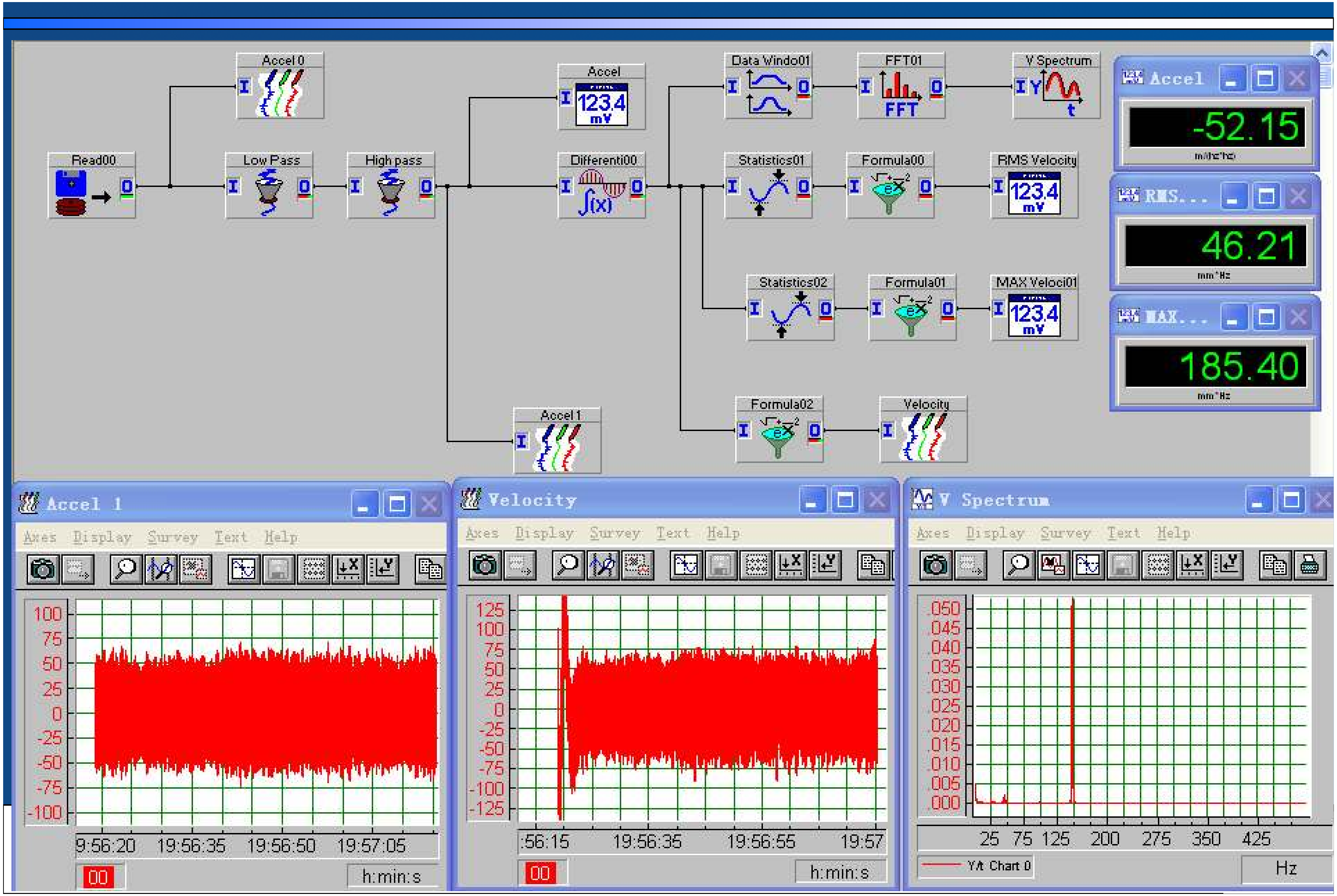
- Vibration testing system:
  - Wavebook 512 data acquisition system
  - B&W accelerators
  - TS7350 filter （Yangzhou Taisi）
  - Low noise cable
  - PCB charge amplifier
  - Analysis software： DasyLab5.6



Application of velocity assessment method



Signal Processing Module



Evaluation results

Table 1 Assessment procedure for 2100 small bore pipes

Project name	Pipe numbers
Total number of small bore pipes	2100
Concerned pipes-by functional analysis	926
Pipes needing vibration measurement	326
Pipes having peak velocity over 12.7 mm/s	67
Pipes having effective velocity over 12 mm/s	15
Pipes having effective velocity over allowable value	8

Evaluation results

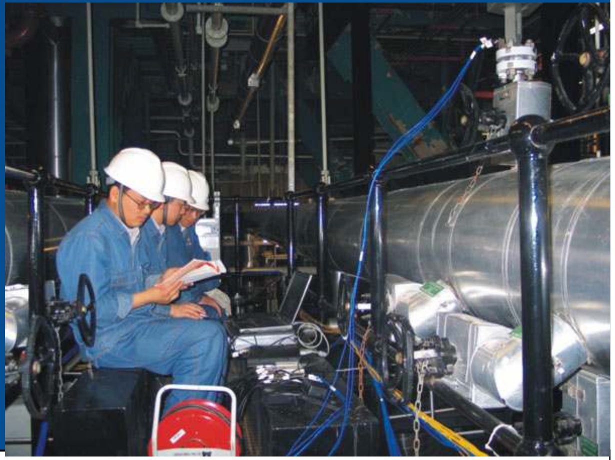
Table 2 8 small bore pipes having effective velocities over allowable values

Number Of Piping	Functional role	V^{rms} (mm/s)	V^{rms}_{allow} (mm/s)
PIPE01	DRAIN TO LIQUID WASTE COLLECTION SYSTEM	50.37	4.96
PIPE02	DRAIN TO LIQUID WASTE COLLECTION SYSTEM	38.11	27.52
PIPE03	DRAIN TO LIQUID WASTE COLLECTION SYSTEM	55.46	25.01
PIPE04	DRAIN TO LIQUID WASTE COLLECTION SYSTEM	16.9	13.34
PIPE05	MAIN STEAM. TO FEED WATER PUMP TURBINE	23.71	9.23
PIPE06	DRAIN TO TURBINE BYPASS SYSTEM	18.74	13.74
PIPE07	DRAIN TO TURBINE BYPASS SYSTEM	14.85	12.61
PIPE08	SITE DISPLAY AND MAIN CONTROL RECORD	22.28	18.19

- **25% pipes have allowable effective velocities lower than the scree ning value (12mm/s)**

Conclusion

- Peak velocity criterion is more conservative than effectiv e velocity criterion ；
- Considering the numerical integral error and stead state vibration condition, effective velocity is more representat ive than peak velocity for stead state vibration ；
- Effective velocity criterion is not conservative for all pipes. Important pipes with high level vibration may be missed during the screening process.



Future Work

- ❑ Dynamic stress measurement and assessment;
- ❑ Piping vibration mitigation measures research and practi ce;
- ❑ Coupled multi-physics analysis considering FSI and ther mal stress;
- ❑ Technical supports on establishing piping vibration asses sment standard for Chinese Nuclear Power Plants;

Thanks for Your Attention ！