

Scoping Testing for the KAFD Mid Grid Proposals

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ABSTRACT

It is important to understand correctly the hydraulic characteristics, including high frequency vibration, of mid grid in developing of new type of fuel assembly for its integrity. Two series of scoping tests were performed in the Vibration Investigation of Small-scale Test Assemblies (VISTA) loop, which is located at the Westinghouse Nuclear Fuel Columbia Site, in support of the development of the KNFC Advanced Fuel Design (KAFD) mid-grid. Total five candidate mid grid designs were tested under the in-reactor flow condition and the room temperature. The tested mid grids are 5x5 portion cut from a full size. Pressure differentials, high frequency vibration and its amplitude of grid strap of each candidate were measured. The effects of parameters, such as mixing vane, dimple shape, spring-rod contact area, window, chamfer/coin and internal intersect welding on the grid strap of each candidate, were investigated also from the test results. It is found that the pressure drop and the vibration amplitude could be reduced dramatically by adding chamfer/coin and removing internal intersect welds on the grid strap.

1. Introduction

Two series of scoping tests were performed in the Vibration Investigation of Small-scale Test Assemblies (VISTA) loop, which is located at the Westinghouse Nuclear Fuel Columbia Site, in support of the development of the KNFC Advanced Fuel Design (KAFD) mid-grid. . The tested mid grids are 5x5 portion cut from a full size grid.

The objectives of the tests are to investigate the hydraulic pressure differentials, the high frequency vibrations (HFV) and their amplitude of the candidate design concepts. Pressure differential of mid-grid is one of the key parameters in developing new type of fuel assembly for the hydraulic compatibility in the transition core. HFV occurs when natural frequency of grid strap is near the vortex shedding frequency and is considered to be contributor to fuel rod fretting.

Series #1 tested five candidate mid grid designs. The candidate grids had no coining or chamfers. Series #2 tested two of the candidate designs to evaluate the effect of coining, chamfers, and removal of internal intersect welds. Specific objectives are listed below:

- (a) Pressure differential measurements of candidate design concepts of mid-grid.
- (b) Vibration frequency and amplitude measurements of grid strap at in-reactor flow rate.
- (c) Sensitivity study of dimple shape, spring-rod contact area, internal welding and chamfer/coin on hydraulic performances of candidate designs.

2. Hydraulic Test Facility

The VISTA loop is a closed-loop, isothermal, room temperature, hydraulic test loop designed to provide pressure drop data and HFV under the vertical flowing conditions. A flow diagram for the VISTA loop is provided as Figure 1.

The major features of the VISTA loop includes a 760 liter tank located 3.66 meters off of the floor, a 50 hp

single-speed pump, a variable frequency pump drive, a turbine flow meter, and lexan flow housings mounted to a rotatable frame. The tank, which is open to the atmosphere, defines the highest water level for the loop, thus setting the water head on the system. By having a loop open to atmosphere, the pressure in the system is minimized since the only adder to hydraulic pressure losses is the static water head, which is small. This meets a design objective of minimizing the pressure load in the lexan flow housing, which is the weakest member of the entire loop. Note that the rupture disc prevents inadvertent over-pressurization of the system with a maximum limit of 414 kPa.

Another design feature to minimize stress on the lexan flow housing is the use of flexible piping pieces, one just prior to the tee and another connected to the outlet tee. This flexible piping takes the misalignment between the piping and the flow housing/frame assembly. These features are effective as the misalignment can be seen in both flexible pieces.

The loop piping is mostly 10-cm Schedule 80 CPVC, including valves and tees. The piping and components (valve, tees) connecting the pump exit to the inlet tee are made of 10-cm Schedule 40 stainless steel.

2.1 Loop Operation

Loop flow is controlled by a variable frequency pump drive via a remote dial located at the loop. Loop flow can also be controlled at the variable frequency drive using the control panel. The remote dial is set to give the required flow as indicated by the rate indicator of the flow meter. The rate indicator shows the flowrate in gpm. The bundle velocity is determined from the total loop gpm by a direct calculation using the bundle flow area. Note that the bypass valve must be closed to ensure that the flowrate through the test housing is the known total flowrate from the rate indicator.

Pump heat is the only source of heat addition to the system. To control this heat input and keep the loop temperature in the preferred testing range, a heat exchanger in the tank using plant chilled water at approximately 10 °C is available.

2.2 Flow Housing and Pressure Tap Layout

The flow housings for the VISTA loop are all made using the same design concept. The flow housing is a bolted lexan assembly which is designed to provide the appropriate cross-section for the gridded rod bundle, withstand the pressure loads resulting from the required high velocity testing, and provide the appropriate flanges for connection to the VISTA loop. A typical housing is made of four 2.5-cm thick walls, bolted together with a gasket running along the length in a groove to provide the appropriate seal. A 22.9-cm circular flange (also 2.5-cm thick) is bolted on each end of the wall assembly, with an appropriately cut flat gasket in between the flange and the walls. This housing is approximately 169-cm in total height. The flow housings are designed for a small clearance to minimize bypass flow around the assembly.

The pressure tap locations relative to the grid locations are shown in the tap diagram in Figure 2. The pressure differential measurements were made for the 3rd and the 4th grids only to prevent them from being affected due to the inlet and/or outlet.

3. Test Articles

The VISTA loop and test assemblies are designed to test four representative bundle spans, thus requiring five grids in the flow field. Note that for hydraulic testing, the top (most downstream) grid does not have to be of the same design as the grid design under investigation since this grid is downstream of all measurements. In section 3.1, a general description for all of the VISTA test assemblies is provided. In section 3.2, details of the specific grid designs and fuel assembly arrays are discussed.

3.1 General VISTA Test Assembly

The test assemblies used in the VISTA loop are mini-bundles prototypical of the actual fuel assembly geometry. The actual dimensions (rod OD, rod pitch, grid strap details, etc.) are maintained, but the test assembly is of a smaller array size and is shorter than the actual fuel assembly geometry. The arrays tested are 5x5' s. The heights of the test assemblies are ~203 centimeters, with 169 centimeters in the bundle flow region.

The test assemblies are easily constructed and components easily reused. Assembly fabrication and breakdown is done by hand with no need for special tooling or fixtures. There is no simulated bottom or top nozzles attached to the test assembly.

Each test assembly consists of the following components:

- 5 test grids (only inner strap tested), which are in the bundle flow region
- 1 support grid which is not in the bundle flow region
- hollow test rods which are sealed with endplugs
- instrumented rod (containing bi-axial accelerometers for HFV testing)

Details of the positioning of the simulated fuel rods and instrumented rods (with accelerometer) are shown in Figure 3. The rods are designed to fit with a minimal clearance between the flow straightener plate and the top plate in the VISTA loop. Four of the hollow test rods are designed with threaded endplugs on one end. These endplugs are designed to go through the top plate to hold the bundle from this plate if needed. Typically, no nuts are put on these endplugs, and they are used for alignment of the bundle with the test housing.

The instrumented rod was also designed with a threaded endplug on the bottom end, with the instrument leads going out the top end. The instrumented rods are shorter than the other rods to allow clearance for the instrument leads to be directed through the top plate. The endplug fits through the flow straightener plate and a nut is attached to hold the accelerometer rod axially in the bundle. This prevents the rod from moving downstream during testing and crushing the instrument leads against the top plate.

To control the axial position of the grids in the flow conditions, pins perpendicular to the flow are inserted into 3 or 4 hollow corner test rods (Figure 3). These pins are located downstream of the top of the grid to hold the grid from moving downstream (i.e., vertically up the assembly) during the axial flow testing. In addition, on two of the corner rods, pins are also located upstream of the grid to aid in bundle fabrication and ensure proper location of the grids prior to testing

3.2 Candidate Mixing Vane Grid Design Concepts

Each cell of the proposed design has a diamond shape spring and two dimples with mixing vane. Following effects on the hydraulic performance were investigated through the tests.

- Window: closed or open
- Spring-rod contact area: wide or normal
- Dimple shape: conformal or normal

Total five candidate grid designs are tested in Series #1 by combining above features. Table 1 provides a list of the proposed designs, which are defined in Figure 4.

4.0 Test Conditions

The primary control variable is the bundle velocity, which ranged from 3.0 to 7.5 m/sec.

The loop pressure was maintained below 413.7 kPa in the horizontal piping just upstream of the test section to protect the mechanical integrity of the lexan flow housing joints. Protection against over-pressurization of the loop is provided by the rupture disc.

To maintain constant fluid density, the test section temperature was maintained at 21 ± 1 °C by manually adjusting the plant cooling water flow to the reservoir. Otherwise, pump heat input would have increased the loop temperature. Table 2 presents the test matrix.

5.0 Data Acquisition and Calculation

5.1 Hydraulic Testing

Pressure drop measurement data were recorded manually from VISTA loop instrumentation for the condition defined in Section 4.0. The data recorded is:

- Bundle velocity
- Loop temperature in the inlet piping if different that 21 °C

- Pressure differential measurements from the pressure transducers

5.2 High Frequency Vibration Testing

Accelerometer, vibrometer and acoustic measurements of the high frequency vibration at the grid strap were made for the range of bundle velocities defined in Section 4.0.

The high frequency vibration data is acquired at the 4th grid. This is the axial position for the location of the bi-axial accelerometer in the instrumented rod, the attachment holes for the housing accelerometers in the outer housing wall, the position at which the microphone is held against the outer wall, and the grid at which grid strap motion measurements were taken with the vibrometer.

5.3 Data Calculation - Loss Coefficients

The observed values of pressure drop and loop flow at the different test measurements were converted to hydraulic loss coefficients by means of the equations presented in this section. Pressure loss coefficients and Reynolds numbers are based on the flow area and equivalent diameter of the test fuel assembly inside the flow housing.

Flow area:

$$A = A_{Housing} - A_{fuel rods}$$

Equivalent hydraulic diameter:

$$De = \frac{4A}{P_{wetted}} = \frac{4A}{P_{housing} + P_{fuel rods}}$$

Pressure differentials were measured at locations such that pressure loss coefficients could be obtained for the 3rd and 4th test grids. Loss coefficients are represented by equivalent of the general form:

$$K_x = \frac{DP_x}{DHEAD} = \frac{f l_x}{De}$$

The dynamic head The friction factor is calculated from the following equations (assuming 100 microinch roughness):

$$f = \frac{0.25}{[\log\{C_1 - 0.3 C_2 \log(C_1 + C_2)\}]^2}$$

$$C_1 = \frac{0.0001}{3.715 De} \quad C_2 = \frac{16.76}{Re}$$

To extrapolate to $Re = 500,000$, which is a common PWR operating condition, a power fit of the data was made using 'Least Square Fitting Method' in the form: $K = A * Re^B$, where A and B are constants.

6.0 Results and Conclusions

The hydraulic characteristics and the high frequency vibration of the KAFD mid-grid candidate designs are investigated from the VISTA loop test results. The pressure differentials and the grid spring vibrations and amplitudes were measured under the in-reactor flow conditions. The pressure loss coefficients for each candidate design from Test Series # 1 and 2 are plotted as a function of flow velocity in Figures 5 and 6, respectively. The loss coefficients extrapolated to $Re = 500,000$ are compared in Table 3. The measurement data of grid spring vibration frequency and amplitude are plotted in Figures 8 to 11. The measure data for the in-reactor flow condition (5.0 ~ 6.0 m/sec of flow velocities), mainly, were investigated.

Important results are as follows:

1. Design concepts with conformal-contact dimple shape have larger pressure loss coefficients. Dimple shape is the sensitive parameter for pressure drop (Fig. 5).
2. Spring-rod contact area and window have negligible effects on pressure drop (Fig. 5).

3. Approximately 17% increase in pressure loss coefficient for mid grid proposals due to mixing vane (Fig. 5).
4. Chamfer/coin on grid strap is a very effective way to reduce the pressure loss coefficients of the mid-grid. The pressure loss coefficients of concepts 2 and 5 in slip-fit cell condition have reduced by ~26% (Fig. 6).
5. Generally, the vibration frequency of grid spring increases steadily as flow velocity increases in the tested flow conditions (Fig. 7).
6. Chamfer/coin on the grid strap has negligible effects on the vibration frequency. But the vibration mode changes in the case of removing internal intersect welds (Fig. 8).
7. The vibration amplitude is reduced dramatically by removing internal intersect welds in the grid strap (Figures 9 and 10). But adding chamfer/coin only with internal intersect welds has the vibration amplitude increased steeply. It needs to further investigation.

Nomenclature

A	Test flow area of fuel assembly, in ²
\boldsymbol{n}	Fluid viscosity
V	Bundle velocity
Re	Reynolds number defined by $(Re = V D_e / \boldsymbol{n})$.
De	Equivalent hydraulic diameter of cross-section area A
$DHEAD$	Dynamic head
f	Friction factor
DP_x	Pressure differential measured by differential pressure transducer “x”
l_x	Friction length of fuel rod bundle in measurement zone of DP_x
K_x	Pressure loss coefficient derived from DP_x
P_i	Wetted perimeter

References

- J. T. Kwon, “5x5 KAFD VISTA Loop Prospectus – Scoping Testing for the Mid Grid Proposals,” (2000).
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Table 1. Proposed Design Concepts

Parameter	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Fuel rod pitch, in	0.506	0.506	0.506	0.506	0.506
Fuel rod dia., in	0.374	0.374	0.374	0.374	0.374
Strap thickness, in	0.018	0.018	0.018	0.018	0.018
Strap height, in	1.500	1.500	1.500	1.500	1.500
Dimple shape	Normal	Normal	Conformal	Conformal	Conformal
Spring shape	Diamond	Diamond	Diamond	Diamond	Diamond
Spring-rod contact area	Normal	Wide	Normal	Normal	Wide
Window	Open	Open	Open	Closed	Closed
Grid envelope, in	2.548	2.548	2.548	2.548	2.548

Table 2. Test Matrix

Series #1: wo. chamfer/coin							
Test I.D.	1-1	1-2	1-3	1-4	1-5	1-6	1-7
Design Concept	5	5	4	3	2	1	Same as
Cell Condition	tight	Slip	slip	slip	slip	slip	Test 1-2
Slot	down	Down	down	down	down	down	but
Internal Welding	yes	Yes	yes	yes	yes	yes	no vanes
Series #2: with Chamfer/coin							
Test I.D.	2-1	2-2	2-3				
Test Condition	Same as Test 1-2	Same as Test 1-5	Same as Test 1-2				
Internal Welding	yes	Yes	no				

Table 3. Pressure Loss Coefficients at Re = 500,000

Series #1: wo. chamfer/coin							
Test I.D.	1-1	1-2	1-3	1-4	1-5	1-6	1-7
Loss Coefficient	0.826	0.818	0.805	0.801	0.748	0.786	0.701
Series #2: with Chamfer/coin							
Test I.D.	2-1	2-2	2-3				
Loss Coefficient	0.589	0.558	0.587				

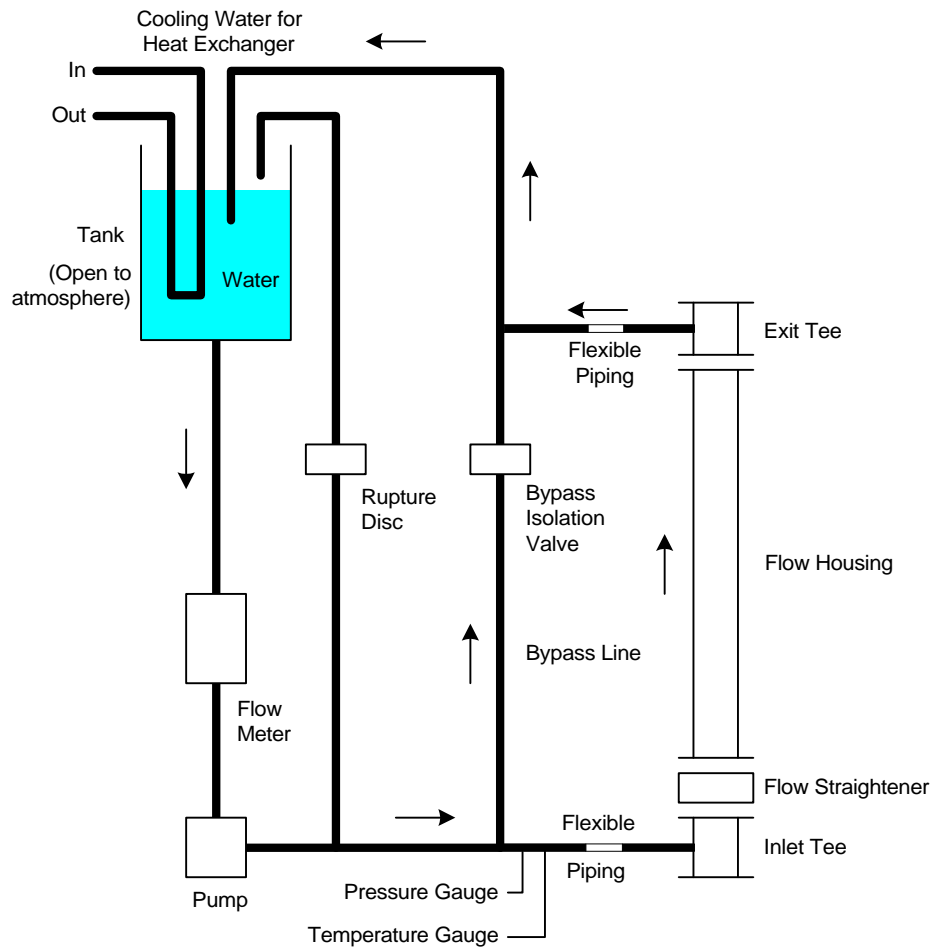
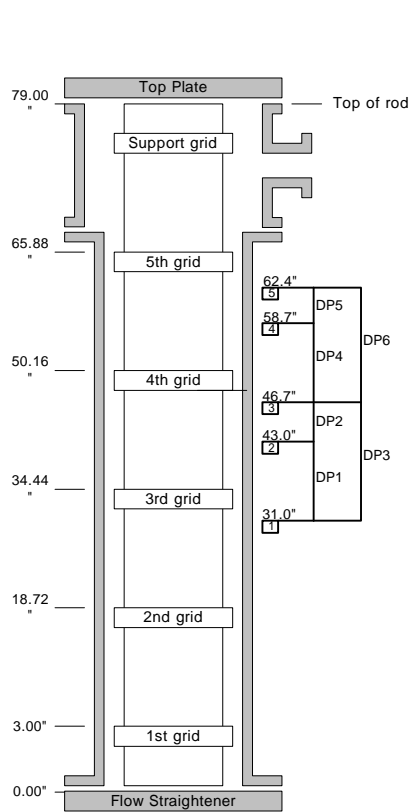
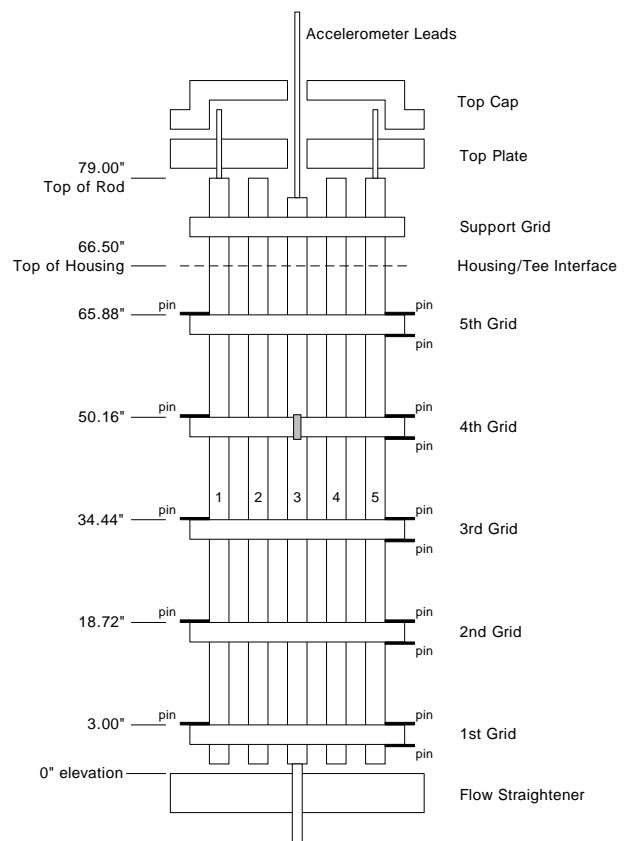


Figure 1. VISTA Flow Diagram



Sketch is not to scale.

Figure 2. Pressure Tap and Grid Locations



Note: Sketch is not to scale.

Figure 3. VISTA Test Rod Geometry

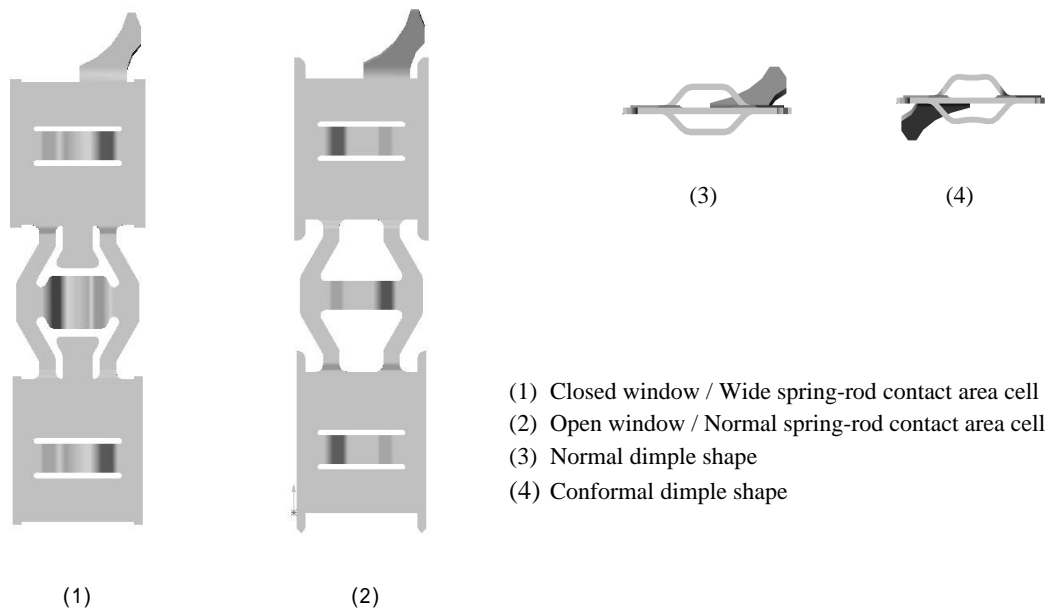


Figure 4. Mid Grid Design Concepts

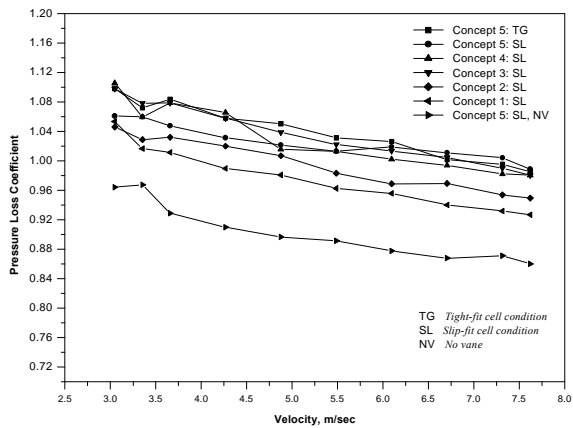


Fig. 5 Pressure loss coefficients of candidate designs

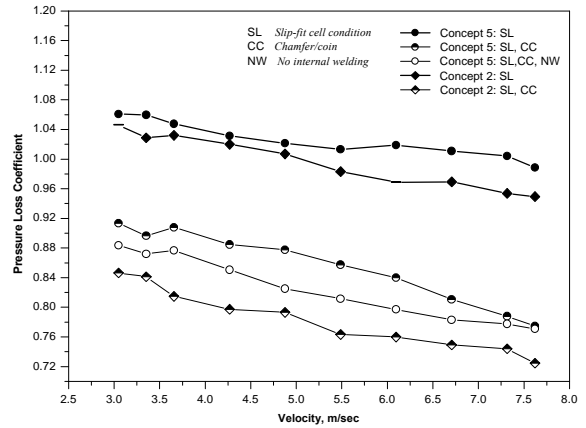


Fig. 6. Chamfer/coin effects on pressure loss coefficient

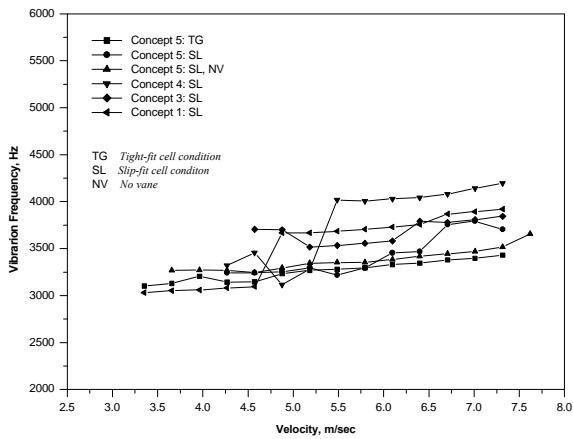


Fig 7. Vibration frequency of grid spring

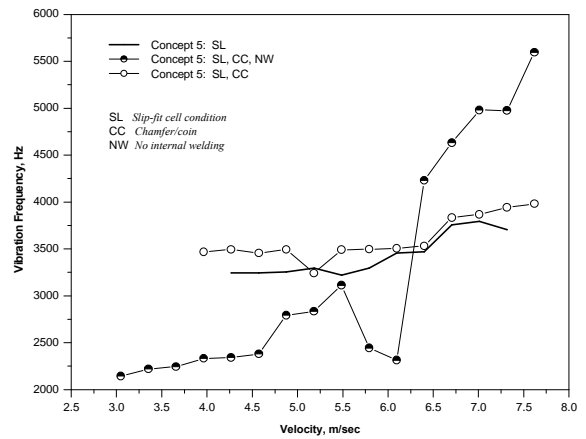


Fig 8. Chamfer/coin & internal welding effects on grid strap vibration frequency

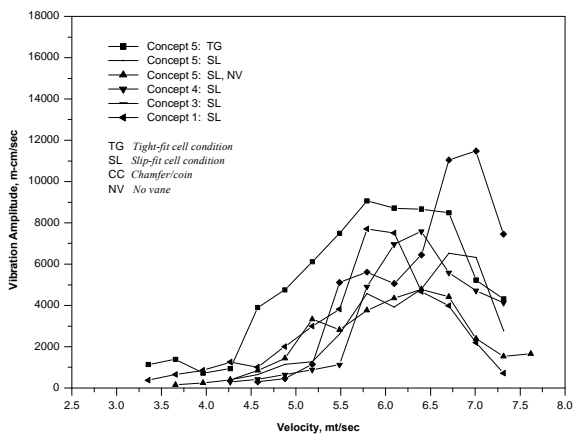


Fig. 9 Vibration amplitude of grid spring

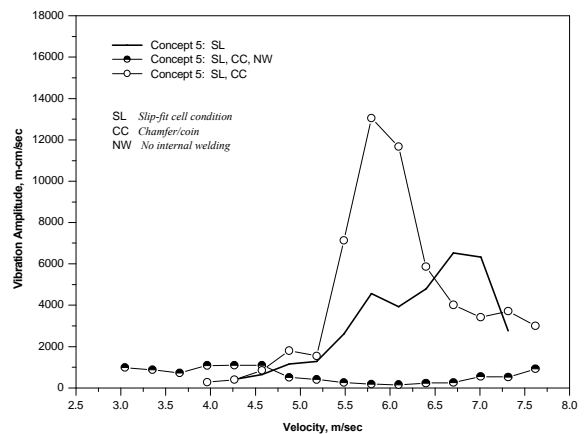


Fig. 10 Chamfer/coin & internal welding effects on grid strap vibration amplitude