

Effect of Snubber-Array on Variation of Pressure Characteristics in Reciprocating Hydrogen Compression

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Abstract : Hydrogen energy is becoming popular day by day due to its renewability and pollutant free natures. Hydrogen gas pressure which is after passing through reciprocating compressor part has high pulsation wave form. A unit, snubber is used as compressor components to reduce the harmful pulsation waveform and to remove the impurities in the hydrogen gas. An experiment has been conducted to investigate the pulsation reduction performance of different arrangement of snubber i.e. snubber array used in reciprocating compression system. Analyzing the snubber array experimental data, it is found that the pressure fluctuations are reduced from 90.1977% ~ 92.6336% with pressure loss 1.5013% ~ 4.9034% for compressor operation at different speed which ensure the good performance of snubber-array as pulsation damper in hydrogen compressing system.

Key words : Root Mean Square, Snubber array, Pressure variation, Reciprocating Hydrogen Compression

1. Introduction

Due to rapid exhaustion of fossil fuel by its diversified increased uses for increased population of the world, its harmful effects on environment, energy capturing politics of different countries, and recent hikes in the price of fossil fuels have added impetus to the movement towards alternative fuels. Thus, green energy based hydrogen system can be one of the best solutions for accelerating and ensuring global stability and sustainability. Therefore the production of hydrogen from non-fossil

fuel sources and the development and application of green energy technologies are becoming crucial in this century for better transition to hydrogen economy [1]. The assertion of "hydrogen is considered a promising future fuel for vehicles" is based on three main arguments: the potential reducing greenhouse gases from the transport sector, greater energy supply security, i.e. hydrogen can be produced from many energy sources and hence the risk of shortage of supply may be reduced; the potential of zero local emissions with

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the use of fuel cells. The absence of hydrogen infrastructure is seen as major obstacle to the introduction of hydrogen FCVs. A full scale hydrogen infrastructure with production facilities, a distribution network and refueling stations is costly to build. The venture of constructing a hydrogen refueling infrastructure constitutes a long-term, capital-intensive investment with great market uncertainties for FCVs. Therefore, reducing the financial risk is major objective of any long-term goal to build a hydrogen infrastructure [2].

All fuel cells currently being developed for near term use in road vehicles require hydrogen as a fuel. While hydrogen can be produced onboard the vehicle by reforming methanol or gasoline, direct storage of compressed gaseous hydrogen has many attractive features. They are simpler vehicle design, less costly and more energy efficient, refueling can be accomplished rapidly, and hydrogen can be produced from many sources [3]. The relative simplicity of vehicle design for the hydrogen fuel cell vehicle must be weighed against the added complexity and cost of developing a hydrogen refueling and infrastructure. Unlike gasoline and natural gas, hydrogen is not widely distributed to consumers today, and refueling a large number of hydrogen vehicles poses significant challenges. One of the most important processes in the hydrogen gas handling is the compressing system. This process is needed in all step of hydrogen gas energy utilization: production, storage, distribution until using [4]. In addition since hydrogen will replace the role of fossil fuel, so all

approach done in this field should be rewarded. In industrial application, hydrogen gas compressing system is frequently used as the transferring or storing force device. It needs high pressure condition; so high working compressors are required. Therefore, usually reciprocating type is used. Some aspects affecting performance of the compressor occur in the suction passage. Since this is the gateway of the gas before entering the cylinder to be compressed. Here the gas is firstly conditioned by means of its structure. Distortion occurred inside inlet flow can be in static pressure or stagnation pressure, but most common distortion is stagnation pressure. Such distortions often occur naturally because of the unsatisfactory nature of the inlet or because of operational effects. The distortion pattern is normally non-uniform in the circumferential and the radial sense. Circumferential seems to be the most serious [5]. The specific objective of this paper is to study the effect of snubber-array in reducing pressure pulsation induced during compression.

2. Experimental setup and method

In the network's model, compressing system takes an important part of whole system. Generally, hydrogen compressor is reciprocating two-stage type. Illustration of the real Hydrogen compressing system is shown by Figure 1. From that figure, the snubbers applied to each compressor stage can be seen clearly.

This works with two consecutive compressing stages which intercooler heat exchanger between them. The cylinder volume of the

2nd stage is smaller than the other, but it has higher operating pressure. In order to damp the pressure fluctuation a flat plate is inserted inside the snubber. This plate is called buffer. The installation of a buffer inside a snubber model can be seen in the 3D photographic view in Figure 3. An experiment to find out the effect of buffer presence in a snubber had already been conducted and found better performance [6]. Technically reciprocating compressor type has higher pressure increasing than rotating one. On that character this type is used in hydrogen handling both for storing and transferring. Special character of pressure produced by this compressor is pulsation or fluctuation. This phenomenon has a lot of disadvantages not only for the gas itself but also for equipments relating to the system. For this occasion the snubber was designed and used [7]. In several parameters, hydrogen gas has same character with the atmosphere air. Especially to observe the pressure from physical approach (without considering the chemical character), pressured air can be used to represent hydrogen gas.

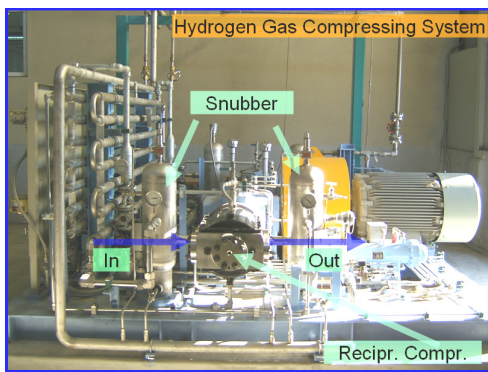


Figure 1: Snubber installation in a hydrogen gas compressing system

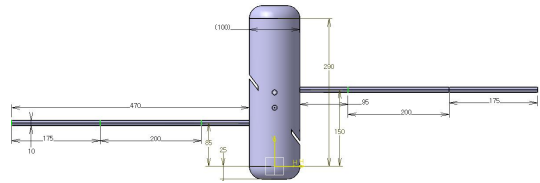


Figure 2: Snubber model dimensions (mm)

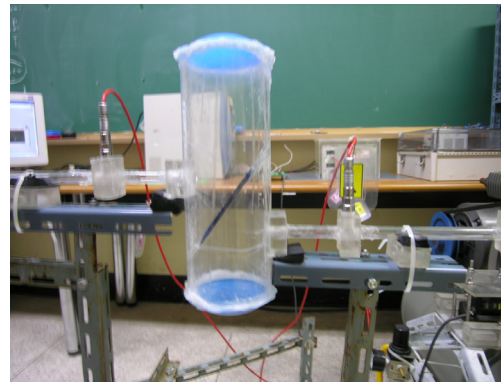


Figure 3: Photographic view of pressure measurement with two sensor at a time

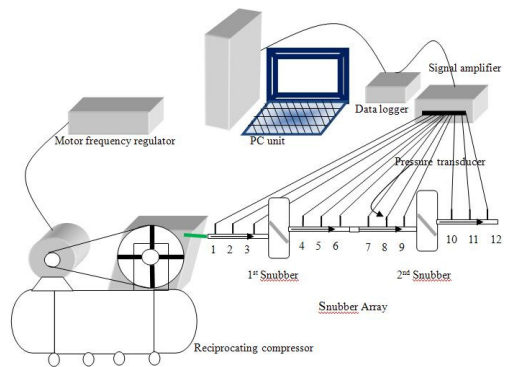


Figure 4: Block diagram of experimental set up of Snubber-array

Different components were constructed and installed together for the experimental setup of snubber-array. The snubber model dimensions were as in Figure 2. Total of twelve pressure sensor points were in the snubber array system as shown by Figure 4. A flat plate of specified height, thickness and width was

located inside the snubber at proper angle and its pictorial view in Figure 3. The setting of different parts was attached to a frame to resist vibrations. The snubber-array was made by attaching second snubber inlet pipe to the first snubber outlet pipe with flexible small hose pipe. The compressor outlet was connected to point 1 with small hose pipe and point 12 was exposed to the atmosphere. The experiment conducted by running the compressor and setting motor frequency at 20 Hz, 30 Hz, 40 Hz and 50 Hz. Pressure from two points were taken at a time as in Figure 6. Pressure values were measured by pressure sensors amplified and recorded them using data logger in a computer.

Motor driven reciprocating pump was used in this experiment. The rotation of motor was controlled by its frequency regulator. The maximum motor rotation was 1800 rpm at maximum frequency (60 Hz). Relationship between compressor and motor pulley rotation were found as in Equation 1.

$$\omega_{comp} [rpm] = f_{set} [Hz] \times 12.84 [rpm/Hz] \quad (1)$$

Then piston in the cylinder will move proportionally with the rotation. The compressing frequency can be written as in Equation (2).

$$f_{comp} [Hz] = f_{set} [Hz] \times 0.214 \quad (2)$$

The periodic action of propelling gas through a pipe by the to and fro movement of the piston in the cylinder in reciprocating compressor caused pulsation.

Piston-crank-valve mechanism generates a variable pressure, which over time creates a composite pressure wave in the suction and discharge pipe. This composite wave is made up of a number of waves. Due to periodic wave generation, multiple frequencies of pulsation are created that causes the force of vibration in the whole system.

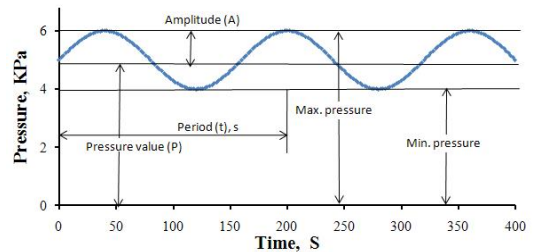


Figure 5: Basic theory of pressure fluctuation

Pressure produced by a piston in reciprocating compressor is fluctuating. Simple description of fluctuating notation is shown in Figure 5. From this figure, pressure value and pressure amplitude can be derived as Equation (3) and (4).

Same with the other gas line utilities, gas that passing through a snubber will be reduced in pressure and reduced in pressure fluctuation. It is related to the amplitude of pressure. The pressure reduction or loss and amplitude reduction can be expressed in the percentage by the Equation (5) and (6), respectively.

$$P = \frac{P_{max} + P_{min}}{2} \quad (3)$$

$$A = \frac{P_{max} - P_{min}}{2} \quad (4)$$

$$P_{red} (\%) = \frac{P_{in} - P_{out}}{P_{in}} \times 100 \% \quad (5)$$

$$A_{\text{red}} (\%) = \frac{A_{\text{in}} - A_{\text{out}}}{A_{\text{in}}} \times 100 \% \quad (6)$$

Experimental data at every section were collected using data logger and analyzed them. Data at section P3 (input side) and section P10 (output side) of the snubber-array system were analyzed for pressure loss and amplitude reduction. The RMS values of input and output of pressure were used for pressure loss. FFT analysis was done to on data to find out amplitude values of the pressure waves along the snubber. The resultant value of the variables was calculated by taking square root of summation of squares of all values [8]. The pressure loss was obtained by equation (5) and the pressure pulsation reduction was calculated by equation (6) using data from experiment.

3. Experimental results and discussion

Total 12 points were selected in the snubber-array for taking pressure data. Motor was operated at 20, 30, 40 and 50 Hz. Figure 6 shows the 50 Hz motor frequency pressure data at point 1 and point 12. Pressure at inlet shows high pulsation with irregular shape but outlet pressure has almost no pressure fluctuation. The wave of pressure fluctuate maximum 119.2064 kPa from minimum 101.6374 kPa considering only large peak excluding all other localized fluctuations in case of inlet pressure at P1. But at point 12, the fluctuations are very less varies from 101.3412 to 101.6014 kPa and there are no other peaks rather than main one.

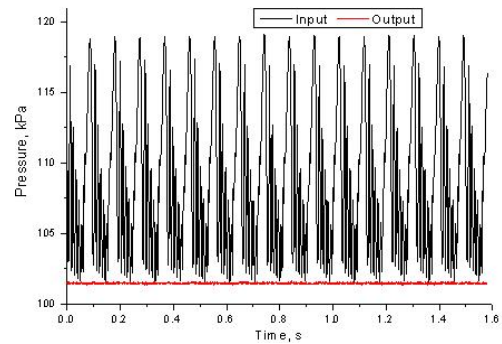


Figure 6: Pressure in the snubber array system at inlet and outlet for 50Hz [P1&P12]

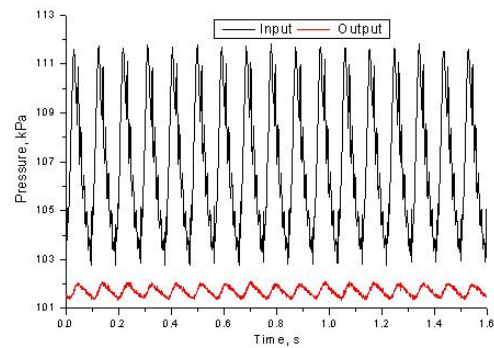


Figure 7: Pressure curve at before 1st snubber and after 2nd snubber in the snubber-array system [P3&P10]

As can be seen in Figure 7, high pressure pulses reduce to lower one due to combine effect of two-snubber between point P3 and point P10. At point P3 of the snubber-array system the pressure wave fluctuation are from 102.7524 kPa to maximum 108.6037 kPa along with some uneven local fluctuations. After passing through some acryl pipe length and two tube unit, this wave downs its pulsation at point P10. The minimum and the maximum pressure fluctuation are 102.1064 kPa and 104.4096 kPa, respectively, for compressor running at 50 Hz motor operation.

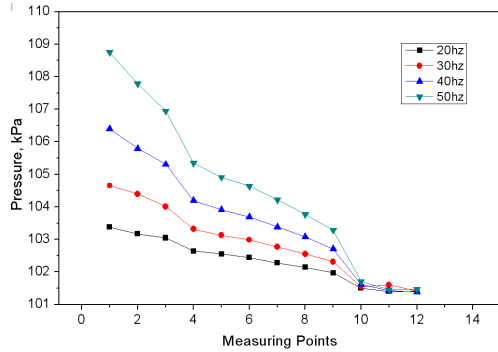


Figure 8: RMS values of pressure along the snubber-array system

The curve showing RMS values of pressure at 4 different motor speeds are presented in Figure 8 for 12 data points of the snubber-array system. First snubber was between point 3 and point 4; second snubber was in between point 9 and 10. For all motor speed pressure drop from point 1 to point 3 were in similar but different values. Due to first snubber pressure reduced abruptly from point 3 and point 4. Acryl pipe have contribute to reduce some pressure for all speed of motor from point 1 to point 3; point 4 to point 9; point 10 to point 12 (outlet) in different values due to its length from the compressor. For 50 Hz motor speed, the RMS value of pressure 108.7495 kPa was recorded at point 1, it came down to 106.9475 kPa at point 3 passing 375 mm length of acryl pipe, it lost some pressure in the tube shape of 1stsnubber and reached at 105.3514 kPa. In the acryl pipe from point 4 to point 10 it lost 2.06469 kPa pressure due to its frictional force. The second snubber reduced the pressure further from 103.287 kPa to 101.7030 kPa.

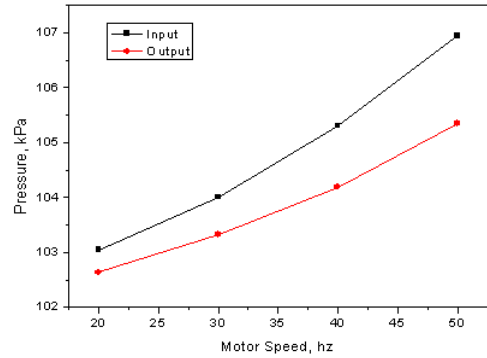


Figure 9(a): RMS values of pressure along 1st snubber in snubber-array system (P3_P4)

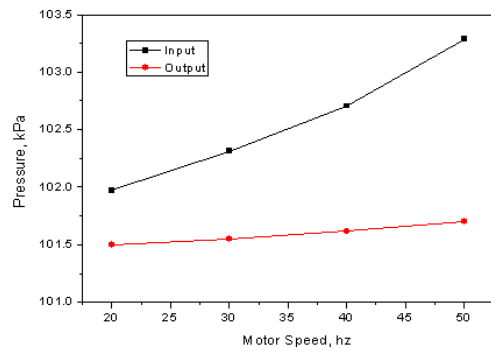


Figure 9(b): RMS values of pressure along 2nd snubber in snubber-array system (P9_P10)

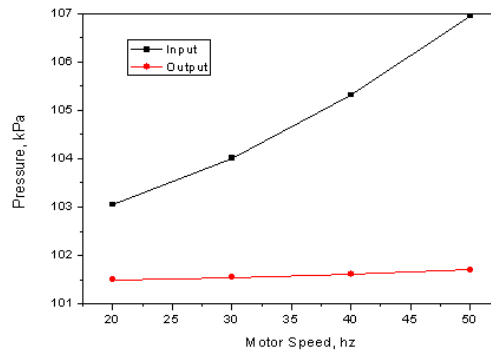


Figure 9(c): RMS values of pressure along the whole snubber-array system (P3_P10)

Inlet and outlet pressure scenario for 1st snubber (P3_P4), 2nd snubber (P9_P10) and whole system ((P3_P10) in

this snubber array system is shown in Figure 9(a) - 9(c). For 1st snubber, the input pressure 103.0464, 104.0076, 105.3066, 106.9471 kPa flowing inside the snubber are reduced at 102.6376, 103.3215, 104.1916, 105.3514 kPa, respectively. The pressure losses are 0.3967, 0.6596, 1.0588 and 1.4920%, respectively for motor speed 20, 30, 40, 50 Hz, respectively (Figure 9(a)). Input pressures are increased with motor speed and output pressure are also increase but in lesser rates. The same is true for 2nd snubber (P9_P10) also. Here input pressure line has more steeper slope than output pressure (Figure 9(b)). The influence of snubber-array on pressure loss is clearly demonstrated in Fig 9(c). The steep pressure line is the input for snubber array system and results a very flat the output pressure line. The reciprocating compressor generated pressure 105.3066 kPa at snubber-array inlet was then reached at 101.6175 kPa due to snubber-array at 40 Hz motor speed. The percentages of pressure loss were 1.5013%, 2.3615%, 3.5032% and 4.9034% for 20 Hz, 30 Hz, 40 Hz and 50 Hz motor frequency, respectively. The trend of pressure loss was positive correlation to motor frequency. On average the RMS values of input, output and per cent pressure loss were 104.8269 kPa, 101.5928 kPa and 3.0674%, respectively.

The pressure losses in 1st snubber (P3_P4), 2nd snubber (P9_P10) and the whole snubber array are 0.9018%, 0.9498% and 3.0674%, respectively, which prove its efficient pressure restoring capacity. After

FFT the amplitude values at each point are plotted against measuring points in the snubber-array system (Figure 10). For different motor speed the amplitude values were in decreasing trend along the acryl pipe due to friction and more reduced amplitude in the tube shape. For 40 Hz, amplitude before and after 1st and 2nd snubber were 1.7186, 1.2347; 0.6094, 0.1509 kPa, respectively. More speed gives more amplitude and amplitude reduction in the snubber-array.

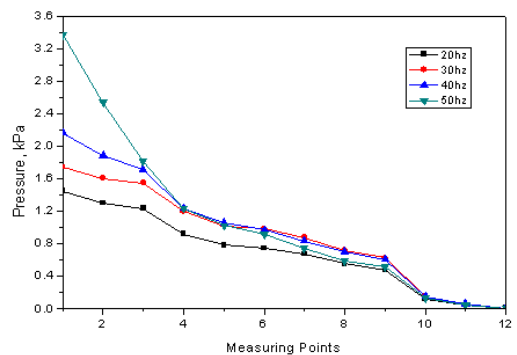


Figure 10: Amplitudes values along the snubber-array

Amplitude values at 1st snubber, 2nd snubber and whole snubber system are viewed in the Figure 11(a), 11(b) and 11(c), respectively. At different motor speed input amplitude pressures at the 1st snubber are 1.2360, 1.5486, 1.7186, 1.8120 kPa and their reductions are 0.9212, 1.1954, 1.2347, 1.2359 kPa inside the 1st snubber. It absorbed 2.4659, 22.8089, 28.1559, 31.7914% pulsation at 20, 30, 40, 50 Hz motor operation (Figure 11 (a)). The 2nd snubber was enclosed by point 9 and point 10. Input amplitude line poses more slope than that of output line formed by plotting amplitude versus motor

operation speed. Amplitude reductions are varied from 74.1547 to 75.7837% when motor speeds are increased from 20 to 50 Hz (Figure 11 (b)).

The amplitude reductions are presented in Figure 11 (c) for 20, 30, 40 and 50 Hz motor frequency in the snubber-array system. It shows the input amplitude, outlet amplitudes and percentages of its reduction for various compressor speeds. Different amplitude values are generated due to compressor effect for different compressor speed. Input amplitude to the snubber-array were 1.2360, 1.5486, 1.7186, 1.8120 kPa whereas the output were 0.1212, 0.1517, 0.1509, 0.1335 kPa for 20, 30, 40 and 50 HZ, motor frequency, respectively. Due to snubber-array the percentages of amplitude reductions were 90.1977%, 90.2045%, 91.2182% and 92.6336% for those speeds. It gives positive increasing amplitude reduction with the motor speed. The average input amplitude, output amplitude and its amplitude reduction were 1.5788, 0.1393 kPa and 91.0635%, respectively.

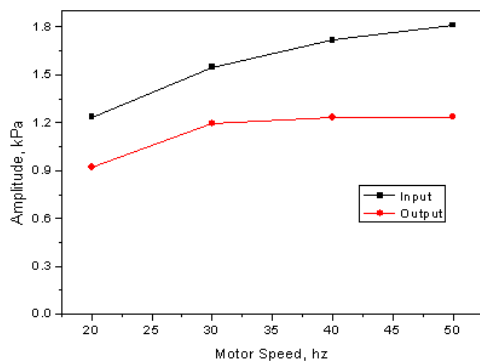


Figure 11(a): Amplitude values of pressure along 1st snubber in snubber-array system (P3_P4)

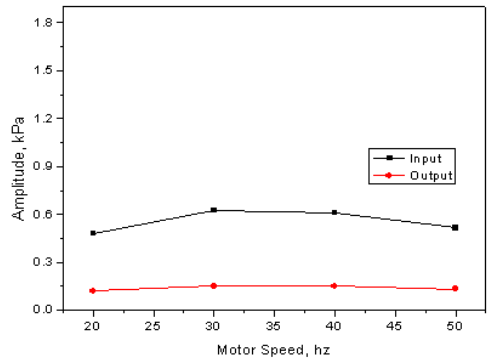


Figure 11(b): Amplitude values of pressure along 1st snubber in snubber-array system (P9_P10)

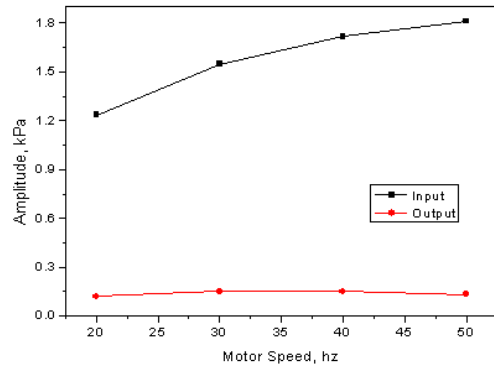


Figure 11(c): Amplitude values of pressure along whole snubber-array system (P3_P10)

4. Conclusions

The present study has shown the pressure characteristics through the single-snubber and snubber-array. Restoring high pressure in both cases but snubber-array plays most efficient role in pressure pulsation reduction than single-snubber. Details are as follows:

1. The amplitude reduction for snubber-array varies from 1.1148 ~ 1.6785 kPa (90.1977% ~ 92.6336%) when average input and output amplitude are 1.5788 kPa, 0.1393 kPa with 1.4395 kPa average reduction (91.0635%) for compressor operation

by motor with 20, 30, 40 and 50 Hz.

2. Pressure losses are varied from 1.5013% ~ 4.9034%, on average, it is 3.0674%, for snubber-array system when the restoring average pressure values at P3 and P10 are 104.8269 and 101.5928 kPa, respectively, with 3.2341 kPa pressure loss for those motor speed. Pressure loss is increased with motor frequency in small amount.

3. Snubber-array system possesses better performance than single snubber system (Rahman, 2006) in reducing pressure pulsation with restoring high pressure.

4. More advance study should be done to carry out the optimization of the problem precisely.

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