Noise Control for Fluid Power Systems

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ABSTRACT

Pressure pulsation, created by the operation of hydraulic pumps in a fluid power system, is one of the primary causes of noise issues from hydraulic machinery. The wave energy resulting from such pulsation propagates in both the wall and the fluid of the flow pipes associated with the fluid power systems, inducing fluid-borne vibration of the pipes and the consequent noise radiated from the pipes. The pressure pulsation can be controlled using many available techniques, including the design of quiet fluid power pumps, active control (e.g. by implementing fluid wave actuators) and passive control treatments (e.g. by installing pulsation suppressor/dampener). This paper presents a case study of noise control for a series of marine hydraulic mooring winch systems installed on a marine barge, which emit excessive noise levels during operation. The installation of passive pulsation suppressors was proposed as the most practical solution to control pulsation from the fluid power units and the consequent excessive noise radiation from the flow pipes, considering a number of factors such as cost, implementation schedule and complexity, as well as intrusion to the system.

Keywords: Fluid Power System, Pressure Pulsation; Noise Control

1. INTRODUCTION

Fluid power systems are widely utilized in a wide range of industries, as fluid is one of the three common means of transmitting power (other means being mechanical and electrical). The basic principle of the fluid power system is to convert mechanical input energy from a power source (e.g. pump) to mechanical output energy at hydraulic equipment (e.g. lifts or winches) via energy transmitted through pressurized hydraulic fluid carried in associated flow pipes (1). Fluid power systems have the benefits of high power transmission, robustness and flexibility. They also have the drawbacks associated with noise and vibration issues.

One of the major mechanisms that causes on-going noise and vibration issues in fluid power systems is pressure pulsation, i.e. the pressure changes, discontinuities and/or variations that occur in the fluid pressure generating action. The pulsation is generally created by pumps of positive displacement type (e.g. vane, gear, radial/axial piston) which deliver a mean flow with a superimposed flow ripple due to the discrete number of pumping elements and the compressibility (i.e. limited stiffness) of the fluid (2).

The wave energy resulting from such pulsation propagates in both the wall and fluid of the flow pipes associated with the hydraulic power systems, inducing vibration of the pipes and consequent noise radiation. The discontinuities of the pipes (e.g. elbows/bends or pipe supports) can result in the coupling of structure-borne and fluid-borne waves, and therefore lead to more complex vibro-acoustic behavior of the pipe systems (3).

Pressure pulsations from fluid power systems have strong characteristics in the following frequency components (4):

$$f = mN / 60 \tag{1}$$

Where m is the harmonic order and N is the rotational speed of the pump in revolutions per minute (RPM). If the number of pumping elements (e.g. vane, gear, piston) is Z, pulsations of order $m = Z, 2Z,$

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3Z,… will be generated, even if the pump is ideally manufactured and operated. In addition, pulsations with order $m = 1, 2, 3,…$ may also be generated due to various causes (e.g. eccentric rotation of the pump shaft, imbalance etc.).

The pressure pulsations are fluid-borne in nature. Therefore, the associated flow pipes generally provide the primary path for noise and vibration propagation from the power units to other components of the system and its radiation to the surroundings. The most effective and direct way of controlling noise and vibration associated with pressure pulsation is to reduce the pulsation levels of the system. The control of pressure pulsation in various industrial scenarios has been intensively investigated and relevant control solutions have been introduced. Some typical control measures are outlined in Table 1.

Pulsations can be controlled to some degree during as early as the pump system design stage via optimizing relevant pump design parameters (2). The pumping system can also be configured with multiple pumps operating in parallel, so that the flow ripples from different pumps will interfere with each other, and subsequently the pulsations can be reduced. There are a variety of passive means that can be applied to control pulsation related noise and vibration (4, 7). Quarter wavelength tube and Helmholtz resonator have proved to be effective but these control devices have to be customized to suit the needs specific to individual systems. Pulsation suppressors/dampers are effective in reducing the pulsation level. However, it may also reduce the mean fluid pressure which would potentially affect the overall performance of the fluid power system. These major passive control measures can be supplemented by other generic vibration control tools (e.g. dynamic vibration absorber and piping supports/clapping) to form a hybrid control solution. Active control via fluid wave actuator has been investigated in recent studies (5, 6), but its practicality needs further testing.

The details of each control measure, including the advantages and limitations, are referred to relevant literature.

Table 1 Pump-induced pressure pulsation in piping systems – typical control measures

Control via pump design (2,4)	Passive control (4,7)	Active control (5,6)
▪ Pump design parameters (for centrifugal pump as an example):	▪ Quarter wavelength Tube	▪ Fluid wave actuator
- Lip clearance	▪ Helmholtz resonator	
- Volute tongue geometry	▪ Pulsation compressor/damper	
- Number of pumping elements	▪ Dynamic vibration absorber	
	▪ Piping supports	
▪ Multiple pumps parallel operation	▪ Hybrid control measures	

This paper presents a case study of noise control for a series of marine hydraulic mooring winch systems installed on a marine barge. The hydraulic winch systems emit excessive noise levels during operation, causing serious health and safety concerns for personnel working in some areas. This case study details the noise and vibration measurements, analyses the cause of the excessive noise emissions from the hydraulic power systems, and thereafter proposes practical noise control methodologies.

2. Case Study Description

2.1 Hydraulic Mooring Winch System

The marine barge associated with this case study is designed to transport export materials from port facilities to bulk cargos. The material discharge process from the barge to a bulk cargo takes place in a designated near shore area where the barge is secured via its mooring system to permanent mooring structures. As part of the marine mooring system, a number of hydraulic mooring winches were installed on the barge deck for controlling the mooring lines. Figure 1(d) shows two adjacent mooring winches on the barge with stored mooring lines. The operation of these winches are powered by their individual fluid power system which comprises a hydraulic power pack (HPP) in the machinery room and its associated flow pipes both inside and machinery room and on the deck area. A HPP unit and its associated flow pipes inside and outside of the machinery area are presented in Figures 1(a) – (c) respectively.

Figure 1 – Marine hydraulic mooring winch system comprised of (a) hydraulic power pack (HPP) unit, (b) & (c) hydraulic flow pipes and (d) mooring winch units.

2.2 Occupational Noise Survey Results

An initial occupational noise survey was carried out when the barge was under normal operating conditions, in order to determine whether the relevant regulatory requirements were compliant, and to identify major noise sources for further treatment/control if required.

The noise survey results showed that the noise levels in some on-board accommodation and workplace areas exceed corresponding noise limits set out by IMO Res A.468 (XII). In particular, it was identified during the survey that the hydraulic mooring winch HPP units and associated hydraulic flow pipes are the major noise sources. The noise radiated from the hydraulic flow pipes significantly impacts the open deck area and some accommodation cabins. It is likely that the vibration of the HPP units also induces structure-borne noise that results in excessive noise levels at internal spaces and surrounding deck areas that are directly adjacent to the HPP machinery rooms.

Figure 2 presents linear and A-weighted overall noise levels and the one-third octave band spectra of a measurement undertaken at a deck area where the dominant noise sources are confirmed as the adjacent hydraulic flow pipes. The one-third octave band spectra of the measurements show that the majority of noise energy is within a relatively high frequency range. For example, the linear spectral levels within all the frequency bands with central frequencies of 200 Hz - 5 kHz are over 60 dB. As a result, both linear and A-weighted overall noise levels are high, but with little difference between the two levels. Substantial energy also presents in low frequency range, as all frequency bands below 200 Hz have the spectral levels above 50 dB. The A-weighted spectrum also displays a strong tonal characteristic of the noise emission, with the presence of tonality in frequency bands with central frequencies of 100 Hz, 250 Hz and 500 Hz.

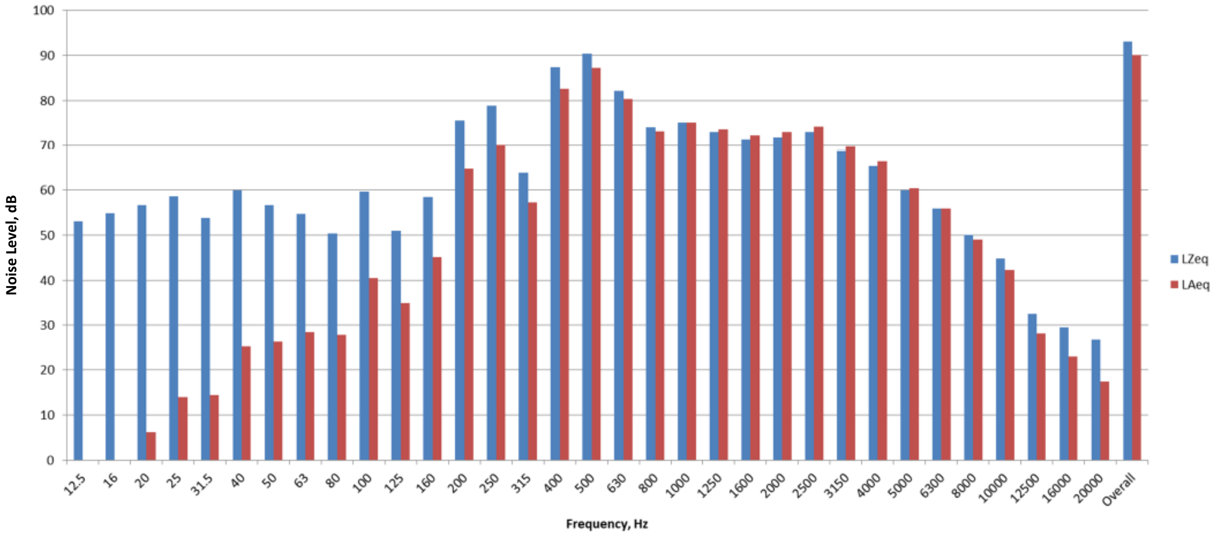

Figure 2 – Linear and A-weighted overall noise levels and the one-third octave band spectra measured for noise radiated from the hydraulic flow pipes.

3. Narrow-band Spectral Measurements

To assist diagnosis and confirmation of noise and vibration generation and propagation mechanisms, narrow-band based spectral measurements were carried out on one hydraulic power system while it was operating without mooring load. A summary of the measurements are listed in Table 2.

Table 2 Narrow-band noise and vibration spectral measurements on fluid power system

Noise or vibration	Measurement locations	Objectives
Vibration	HPP unit and its immediate joint steel structures, including the ground deck and steel wall structures	Vibration transmission from HPP unit to the joint structure, and the consequent structure-borne noise emissions
Vibration	Various sections of hydraulic flow pipes, both inside the machinery room and at the deck area	Characterization of the flow pipes vibration and its transmission/attenuation along the flow pipe sections
Noise	Within machinery room, at internal and external spaces of high noise levels adjacent to machinery room, and on-deck workspace adjacent to flow pipes	Correlation between the noise and vibration spectral contents, and identification of noise transmission paths (i.e. via either structure-borne or airborne)

Based on the spectral analysis of the measurements, as well as the site observations, two major findings are detailed as follows:

1. The predominant noise emitted from the flow pipes is caused by the wave energy resulting from the pressure pulsations propagating along both the fluid-filled pipes and the pipe walls. The evidence to this conclusion is that the vibration of the flow pipes and its noise emission have been characterized with harmonic frequencies with the fundamental frequency of around 220Hz, which is associated with pump operation speed of 1480 RPM (or 24.6 Hz) and number of pumping elements (i.e. 9 pistons). The strong correlation between the vibration of the flow pipes and the noise emissions in regards to their harmonic frequencies are shown in Figure 3 and Figure 4.

2. The HPP units and associated flow pipes are rigidly mounted onto the base deck and walls/decks. The vibration of the HPP units has been effectively transmitted via flow pipes and rigid mounts to the associated structures, causing structure-borne noise that impacts the surrounding spaces.

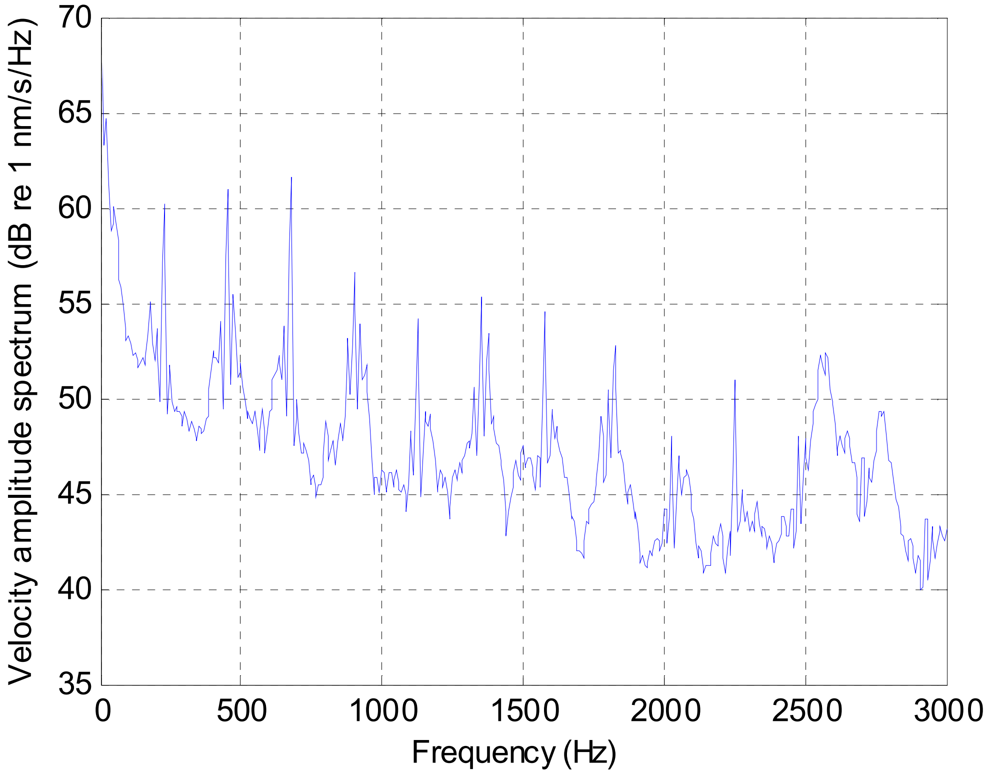

Figure 3 - Measured typical velocity amplitude spectral levels (dB re 1nm/s/Hz) at one position on a hydraulic flow pipe with a 40mm diameter.

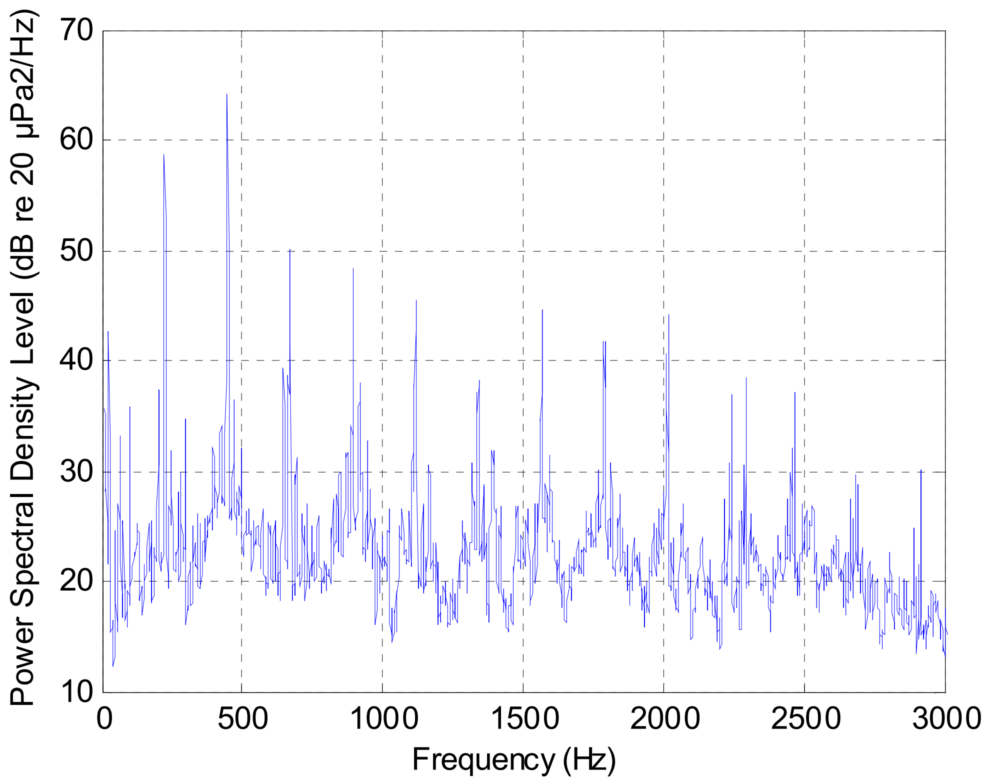

Figure 4 - Power spectral density levels (dB re 20 μPa^2/Hz) of a noise recording measurement undertaken at a deck area adjacent to hydraulic flow pipes.

4. Recommended control measures

In response to the results from the noise and vibration measurements, spectral analysis and site investigations, control measures were recommended to address the identified noise and vibration issues. These measures are outlined in Table 3 and prioritized in a ranking order based on their expected performance. It was recommended that these measures be implemented in stages, with performance verification of the measures after each stage to determine if further treatments were necessary.

Table 3 Recommended control measures in a ranking order based on the expected achievable performance

Ranking	Control measures	Objectives
1	Install pulsation suppressors connecting HPP unit and its outlet flow pipes, supplemented by flexible hydraulic hose connections	Suppress the pressure pulsation due to the pump operations, and consequently reduce vibration levels of the outlet flow pipes and associated noise emissions
2	Replace rigid mounts with vibration isolators for HPP units onto the metal base deck	Reduce vibration transmission from HPP to the base deck, and the consequent structure-borne noise emissions
3	Install flexible joints at the penetrations through the structures (e.g. walls and decks) and replace rigid flow pipe supports by vibration isolation hangers/clamps	Reduce vibration transmission from flow pipes to the joint structure, and the consequent structure-borne noise emissions
4	Lag the hydraulic flow pipes and/or enclose the HPP units	Reduce the noise emissions from the flow pipes and HPP to the surroundings

The installation of suitable pulsation suppressors at the outlet of the hydraulic pumps, in order to suppress the pressure pulsations, is expected to achieve the most significant reduction in vibration of the flow pipes, and consequently the noise emissions. The pressure suppressors are generally of low cost, can be easily installed and maintained, with minimum intrusion to the fluid power systems. Compared with other pulsation control measures listed in Table 1, the advantages of installing pulsation suppressors are considered to be the most beneficial, taking into account the cost, implementation and complexity involved in the scenarios specific to the case study. Examples of suitable suppressors available in the market are the Wilkes & McLean hydraulic suppressors (8).

Vibration isolation treatments are recommended for both HPP units and hydraulic flow pipes, to reduce the vibration transmission, and the consequent structure-borne noise emissions.

Further noise reduction can be achieved via lagging of the flow pipes and enclosures of HPP units, but these measures are least effective and can be costly to implement. Therefore, they are of the lowest ranking among all recommended measures.

5. Summary

This paper firstly introduced pressure pulsations as one of the major mechanisms that cause noise and vibration issues in fluid power systems, its predominant spectral characteristics, as well as the typical control measures. A control study on noise and vibration associated with hydraulic mooring winch systems installed on a marine barge was then presented. The case study illustrated the diagnosis of pressure pulsation as the primary cause of noise and vibration issues for the fluid power systems, based on detailed site measurements and spectral analysis of the measurement results. The installation of pulsation suppressors was recommended as the major control measure, with consideration of the scenarios specific to the case study. The performance of the proposed control measures is to be verified once the implementations of these measures completed.

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