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ACOUSTICS IN DIAGNOSING NOISE AND VIBRATION IN HYDRAULIC TURBOMACHINERY

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1 INTRODUCTION

Interest in noise generated by hydraulic machines and circuits is now growing as manufacturers are being faced with specifications which demand lower noise and vibration limits. The Health and Safety at Work Act 1974 and the Control of Pollution Act 1974 have indicated limits for noise emitted by machinery. The most common and fairly powerful instrument for acoustic diagnosis is the human ear; however, if we wish to extend and improve techniques of acoustic diagnosis, it is desirable to develop new techniques to include sounds outside the frequency range of the human ear. Effective noise measurement and analysis is necessary and the paper will describe the various types of noise generated by pumps and methods of measurement, together with typical problems and reference to work being carried out at NEL. Although this short paper is concerned with hydraulic machinery generally, and pumps in particular, attention is focussed on the special nature of fluid-borne, fluid-generated noise.

2 NOISE GENERATED IN PUMPS

A diagnosis is obtained, as in the clinical field, from a practitioner comparing measured data with what he knows from experience to be normal for that machine, and then assessing the significance of the difference. Generally the final objective is to ascertain that the machine is functioning properly, or to detect the onset of mechanical or hydraulic trouble, thus keeping routine maintenance, or indeed failures, to a minimum.

The noise produced by a pump depends on several factors, including pump geometry, nature of the pumping mechanism, method of pump mounting and installation. The main sources of pump noise are mechanical components, pressure and flow pulsations, and structural movements such as unbalanced rotating assemblies, shaft misalignment and bearings. Pump noise can be divided into three general classes: aerodynamic (or airborne), hydraulic (or fluid-borne) and mechanical vibrations. Aspects of airborne noise and vibration, both from measurement and analytical viewpoints, will be described briefly, as they have been fully dealt with elsewhere[1,2].

2.1 Airborne Noise

The limit on airborne noise from any piece of machinery is usually fixed by hearing conservation criteria. At present the recommended limit is 90 dBA, but in Europe it is 85 dBA, with 90 dBA as the maximum allowable. The operating conditions for a pump are important, and airborne noise is generally least around the pump's best efficiency point. Mechanical sources likely to introduce noise are bearings and drive line couplings, with high-speed couplings being a cause of aerodynamic noise. Noise can be reduced by increased blade loading, which allows lower pump speeds and so reduces tip speeds, an important factor in noise generation in pumps.

Depending on the type of measurement required, band pressure levels (octave bands are generally sufficient) or total sound level (A weighting) should be measured. For initial tests a sound level meter, either with or without external filters, can be used. If more detailed information regarding frequency content is required a more elaborate set-up is necessary. A good quality microphone feeding into a one-third octave band analyser is a common set-up. Additionally, data may be recorded on magnetic tape (perhaps from several microphone sources at the same time) for subsequent analysis. Many airborne noise components in pumps are highly directional; high frequencies are susceptible to reflection and shielding by simple structures.

2.2 Vibration

The vibration response of a pump is greatly dependent on the nature of the forces due to hydrodynamic bearings, neck ring seals, impellers and diffusers. Critical speeds and out-of-balance rotating parts are also common sources of vibration. Many factors are speed dependent, but vibrations may also arise from resonance of adjacent parts such as studs, bed-plates, supports and panels.

Accelerometers are generally used for vibration measurements mounted on, say, bearing housings and pump casing. Care should be taken in the method of mounting the accelerometer. Measurement and monitoring of vibration on bearing housings is common practice and provides valuable information on machine performance. Similar measurements should be made at other points, particularly on large surface areas.

2.3 Fluid-borne Noise

Noise generated hydraulically in a pump falls into three main groups. The first is due to interaction between flow at suction and discharge of the impeller, and the rotating and stationary components respectively. The second is turbulence noise resulting from vortices set up in the flow through the pump. Finally, cavitation noise results from the growth and collapse of vapour-filled bubbles when acted on by surrounding fluid at higher pressures. Cavitation noise has a large high-frequency content, and in its early stages is well above the audible range of hearing, but is nevertheless damaging to a pump.

One of the more important aspects of fluid-borne noise in a pump is its spectrum or breakdown of noise as a function of frequency, rather than the total noise level. In measuring fluid-borne noise, pressure transducers of the piezoelectric type rather than microphones are used. Such transducers should be mounted in the pump casing or pipework where noise measurements are required, flush with the inside wall. Miniature types are preferable, especially if a wide frequency range is to be measured, such as where cavitation noise is concerned. Frequencies up to and above 100 kHz can be measured, and if magnetic tape is used the signal should be recorded in both FM and AM modes to preserve as wide a frequency range as possible (d.c. to >100 kHz). For cavitation noise, especially in its early stages, signals will be extremely low, and good low-noise amplifiers are necessary for proper measurement of such signals. Analysis in one-third octave bands, or even narrower, will be required if it is necessary to investigate sources of noise, such as blade, shaft frequencies and their associated harmonics. A frequency analyser, preferably a real-time one, will be required.

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A typical pump noise spectrogram is shown in Fig. 1. Both non-cavitating and cavitating states are indicated, the difference being noticeable mainly at the high-frequency end of the spectrum.

Fig. 2 shows typical pump noise data, together with a performance curve. The principal noise sources - shaft, blade, and cavitation (high) frequencies - are plotted. As is evident from Fig. 2 high-frequency noise measurements (>10 kHz) are a more reliable indication of whether cavitation is occurring in a pump. Values for typical pumps show that cavitation is present at much higher suction pressures than has often been supposed, certainly long before the machine's efficiency is affected.

Pump noise is principally related to pump tip speed. Fig. 3 shows how the total noise measured on several pumps varies with tip speed. The sound power ratio plotted may be considered to be the ratio of acoustic power flow in the pipe (or inlet) to the hydrodynamic power flow. This ratio has a speed index of 5. It should be noted that as a pump operates across the flow characteristic, not only does the energy rise vary, but the noise output varies; the noise output generally is least at, or near, the best efficiency point.

Impeller blade frequency noise can be reduced by operating near pump duty point, or by increasing the clearance between impeller tip and cutwater. Shaft frequency noise interacts with impeller blade frequency but can often be reduced by careful mechanical design of the pump and pump drive. Cavitation noise is best avoided by careful pump design, operating near duty point and with a sufficiently high NPSE.

3 CONCLUSIONS

Acoustic monitoring of machine performance has the advantage that the measuring devices may be positioned remotely, in areas that may otherwise have been inaccessible for carrying out a diagnosis; transducer signals can be processed to give information on many aspects of machine operation. In general, it is best to keep pump tip speeds as low as possible since noise levels increase with speed, but unfortunately present-day trends are towards higher speed pumps. Structure-borne noise can be reduced by using suitable materials and isolating a pump from its supports. Meeting noise limits imposed by environmental considerations may necessitate enclosing a pump to interrupt the path of noise propagation. Noise generated by cavitation can be a reliable indication of whether cavitation is present in a pump; suppression of cavitation requires suction energy values well above that where head or efficiency is affected.

ACKNOWLEDGEMENT

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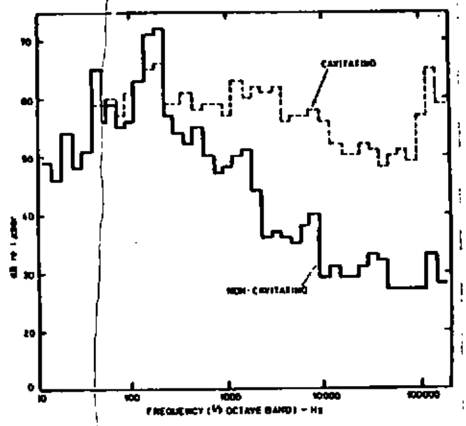

Fig. 1 Typical pump noise spectrogram

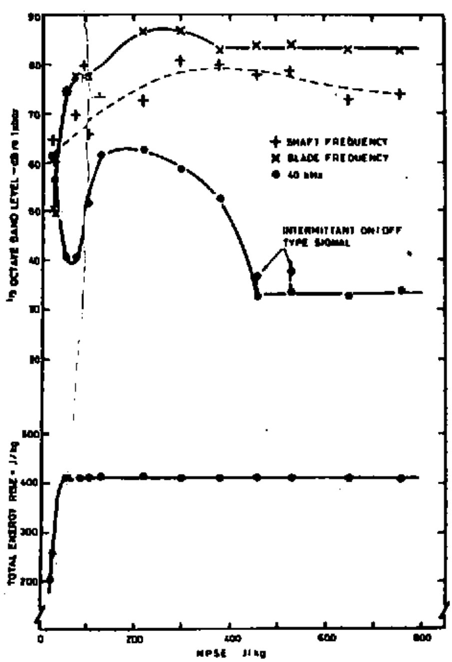

Fig. 2 Typical fluid-borne pump noise, and performance curves

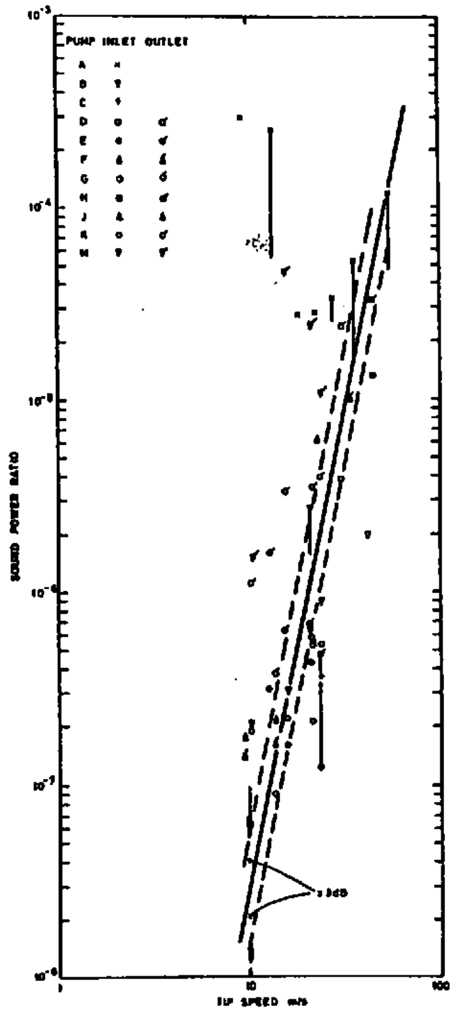

Fig. 3 Effect of tip speed on sound power ratio at best efficiency flow