ACOUSTIC PULSATIONS IN RECIPROCATING MACHINERY

Brian C. Howes, M.Sc., P.Eng. – Chief Engineer
Shelley D. Greenfield, P. Eng. – Supervisor – Acoustical Analysis
Christine K. Schuh, E.I.T. – Project Engineer
Beta Machinery Analysis Ltd., 300, 1615 – 10th Ave. S.W., Calgary, AB, T3C 0J7

1.0 Introduction

High vibration in reciprocating machinery is a common occurrence. Vibration produces alternating stresses in the material. Alternating stress levels beyond the endurance limit of the material causes fatigue failure. Failures of this type can be catastrophic. Consequently, measures are taken to avoid high vibration. Vibrations can usually be attributed to either the mechanical or acoustical design. One key to controlling vibration is the understanding and manipulation of each systems' unique acoustical characteristics.

2.0 Background

Beta Machinery Analysis Ltd. (BMA) began 24 years ago as an engineering consulting firm troubleshooting machinery problems. After several years of field experience, BMA discovered that many problems encountered with reciprocating machinery, and the attached piping, were due to pressure pulsations. In 1972 the company began the development of an acoustical modelling method using a digital computer. Since 1974, we have been providing a digital acoustical analysis service (MAPAK) for reciprocating compressors and pumps. MAPAK (Mechanical and Acoustical Package) analyses two causes, acoustical and mechanical, of vibration and makes recommendations to eliminate potential problems.

3.0 Discussion

Pressure pulsations are generated by the reciprocating action of a piston or plunger. Considering the discharge side of a cylinder, the piston or plunger moves to compress the fluid. Regions of compressed fluid are released into the system when the valves are closed. The same phenomenon occurs on the suction side when the fluid is being drawn into the cylinder. Pressure waves always travel away from the source at the speed of sound of the fluid, regardless of the direction of fluid flow. Because of the cyclic nature of the machinery, compression and rarefaction waves, or pulsations, are sent into the system at regular intervals. Thus, pulsations are inherent to all reciprocating systems and cannot be completely eliminated.

3.1 Effects of Pulsations

High pulsations can affect valve performance, metering accuracy, and system pressure drop.

Pressure pulsations influence the motion of compressor, or pump, valves, and under certain conditions cause erratic valve behaviour. Phenomena such as improper opening and closing events, and valve flutter are typical symptoms of high pulsation. Such phenomena can distort the pressure volume (P-V) curve and affect compressor performance. Some of the negative effects of high pulsation at the compressor valves are degraded compressor performances, and hence capacity, and increase maintenance costs due to premature valve failures.

Pressure pulsations are accompanied by fluctuating flow. Excessive flow fluctuation at orifice flow measuring devices cause inaccurate readings. Readings from such meters are often used to determine the amount of gas bought or sold. Thus inaccurate metering can result in substantial monetary losses.

Another consequence of high fluctuations in the flow is increased system pressure drop. Even though the average line flow of a system with high pulsations is the same as one without pulsation, the oscillating flow component of the high pulsation system produces more pressure drop (due to the squared relationship between flow rate and pressure drop). The greater the pressure and flow pulsations, the harder the driver has to work to produce the throughput of a system with low pulsation.

3.2 Effects of Pulsation on Vibration

Pulsations travelling away from the source are reflected at the discontinuities in the system (i.e. at changes in cross-section, entrances to volumes, dead legs, changes in density, etc.) to form standing waves. Depending on the geometry, and pulsation frequency, amplitude and phase, the pulsation standing wave will either be greater or less than the initial travelling pulsation wave. However, high pulsations do not normally damage a piping system. The interaction of the piping system with the pulsations result in unbalanced forces. These unbalanced forces cause vibration and the vibration in turn produces stress. Alternating stresses beyond the endurance limit will in time cause fatigue failures.

In some cases high vibrations may be acceptable from a stress point of view but are considered unacceptable from a psychological point of view. High vibration, resulting in alternating stresses below the endurance limit, can create an air of 'unsafe' conditions making operators working in the area feel uncomfortable.

3.3 Digital Computer Modelling

Once the system geometry and operating conditions are known, MAPAK can be used to calculate the magnitude and phase of the impedances, pulsations, and volume velocities over the frequency range of concern. Acoustical input is generated at multiples of compressor run speed or plunger passing frequency.

The predicted pulsations, unbalanced forces and metering error can then be compared to guideline levels. If necessary, pulsation suppression devices such as orifice plates, choke tubes and volumes can be added to the system to modify the acoustical characteristics to within guideline. The pressure drop, and hence horsepower loss, introduced into a system by pulsation suppression devices must also be considered.

By using a computer model the best balance of the above guidelines can be determined for the full range of operating conditions expected for the life of the installation. For the installations where not all the guidelines can be satisfied, the initial capital costs and long term operating costs must be evaluated. Based on the economics of the installation it can be determined which of the guidelines is least important.

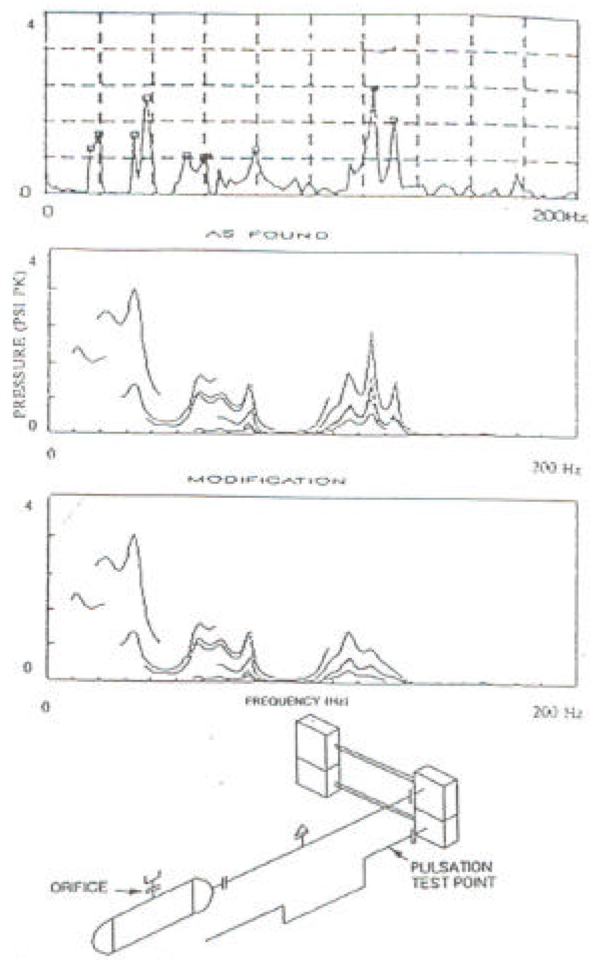
BMA's computer model makes use of the simplifying assumptions of plane wave acoustical theory and an ideal valve model. The plane wave acoustical theory is valid in confined piping systems. At extreme pulsation levels, the acoustical pulsation assumption is not valid. However, as more pulsation control is added the model becomes more accurate. For engineering purposes an ideal valve model is sufficient. Any non-idea valve behaviour can be corrected outside the computer mode. With these assumptions, field data compare closely to predicted pulsations, as shown below.

4.0 Field v.s. Predicted Comparison

The following comparison is for the second stage discharge system of a two stage, two throw, 400 HP reciprocating compressor. The pulsation test point is located just after the cooler. The cylinder passage design was proposed by the manufacturer to act as a pulsation dampener.

Special care was taken in modelling the cylinder passages because of their unique design. This is the only area which was given special attention, the remainder of the system was modelled based on standard techniques employed by BMA in performing an acoustical study.

The first graph is the measured pulsations encountered in the field. The following graph shows the MAPAK predictions. The third graph is the MAPAK model of the same system with the addition of a mild orifice located between the cylinder and bottle nozzle connection. This was added to reduce the pulsations at the higher frequencies.



Another area of concern is accurate measurement of flow. Using MAPAK to determine what volume velocities will occur at a metering device enables the metering error due to pulsations to be predicted. The following comparison is for a single stage, two throw, 1680 HP reciprocating compressor.

Metering error varies with speed. Depending where in the speed range the compressor is operating, the metering error may be high or low. In this case, at 710 RPM, the metering error corresponds to what was measured in the field.