I'm picking up good vibrations

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outline the value of measuring and understanding electro-mechanical vibration activity.

Under most circumstances, an event occurring 130 million years ago and lasting but a few seconds, would not be considered news. Yet it happens, and sometimes it is not the significance of the event, but the observation which must be considered most remarkable. In 2015, scientists made the first ever observation of a gravitational wave. The wave observed nearly simultaneously at detectors in Louisiana and Washington, US, was created in a cataclysmic merging of two neutron stars 7×10^{14} million miles from Earth. The observation of the collision of the rotating binary system gave researchers proof of the existence of what was, until then, just theorised oscillations in space-time. This wave is a four-dimensional electromagnetic oscillation. The oscillation produced microscopic, yet detectable vibrations in the Earth itself. The scientific genius of this experiment and the events

witnessed earned physicists Weiss, Barish and Thorne shares of the 2017 Nobel Prize in Physics and at the same time irrefutably proved general relativity.

Not all vibration events are so monumental. Vibration is no more than the movement of a body about its mean position and is completely defined by its amplitude and frequency. There are other parameters which may be used to describe a vibration; energy, acceleration, velocity and displacement are some, but all forms reduce to the previous two. Physical vibrations may be linear, circular or irregular in shape and frequency, but to be of value to an observer, the vibrational melody must be measurable. Vibration and oscillation are found in all systems, including electro-mechanical systems, likely the most familiar to the readers of this article, but also biological, chemical and many more.

Sound is oscillating pressure; a song sung in the form of a varying wave moving in time created by the vibration of an object. Like ripples on the surface of a pond propagating from the point of entry of a thrown pebble, or notes of a symphonic composition, any mechanical body moving in a fluid transfers energy to its surrounding medium creating travelling waves moving from the body in all directions. Pitch is modulated by frequency. Volume is a function of amplitude. Frequency is measured in Hertz (Hz). Volume, an analog for power, is measured in decibels (dB).

Figure 1. High speed direct-drive motor-compressor (18 MW, 5460 RPM).

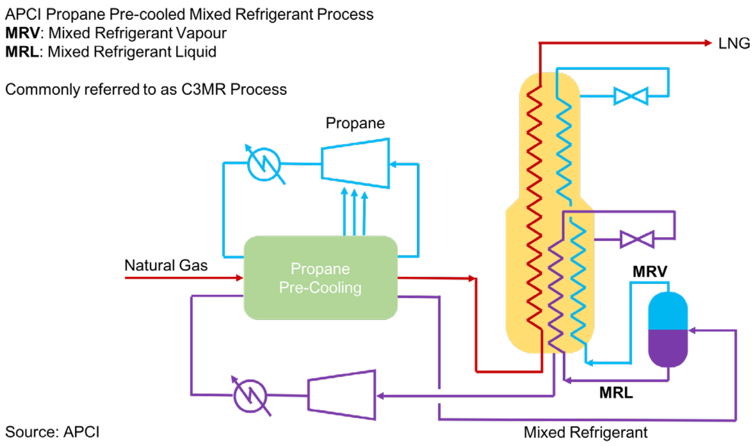

Figure 2. C3MR process.

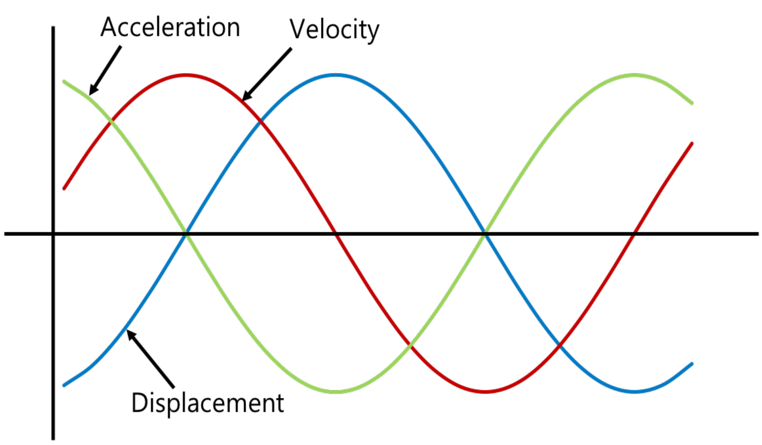

Figure 3. Phase relationships among displacement, velocity and acceleration.

Electric motor drives for LNG plants

Compression systems in their most fundamental form combine a prime mover and driven equipment. Gas and steam turbines remain a stalwart of very large rotating systems. For LNG applications, the largest prime movers are turbines or turbines with electric helper motors from 10 MW to 45 MW. However, as electrical utility systems grow more robust and large medium voltage variable frequency drives become increasingly reliable, electric motors more so become the choice of prime mover for large rotating systems (Figure 1).

The first ever all-electric drive in an LNG plant, Snohvit LNG, commissioned in Norway in 2007, utilises three 70 MW electric motors. Also, the soon to come online Freeport LNG production and export facility at Quintana Island, Texas, chose electric motors for its "efficient, reliable and simple operations with long maintenance intervals", in addition to its ability to minimise air emissions. This facility incorporates three 75 MW electric motors with variable frequency drives for the propane and mixed-refrigerant compressors. Freeport LNG utilises an Air Liquide CM3R process, one of many processes also favoured by ConocoPhillips, Shell GSI, Statoil-Linde and Black and Veatch (Figure 2). All processes require rotating equipment in many forms. Electric motors are also the choice for auxiliary LNG services end flash gas, boost and fuel gas compressors, gas treatment plants and CO_2 injection applications.

Principles of machine vibration

Turbines, compressors, gearboxes and electric motors, in fact any rotating or reciprocating body, will vibrate regardless of how precisely designed and manufactured. Forced vibrations in mechanical systems are a chief source of energy loss and contribute substantially to failure due to wear and fatigue.

All vibrations are either forced or natural. A tuning fork is an example of a free vibration. Once struck, a tuning fork will vibrate at its natural frequency until the motion is dissipated as heat into the medium in which it vibrates. A piston in a reciprocating compressor or an imbalance in the rotor of an electric motor is an example of a forced vibration. The energy for the force excitation is provided by electrical power applied to the system. It is arguable that an electric motor is mostly a mechanical machine with a little electrical thrown in. Hence, the physical behaviour of the system can be approximated with free body diagrams. This simplified model is used to predict system response as a function of excitation force. Excitation is a function of amplitude and frequency. Response is a function of mass, stiffness and damping of the body. In most cases, finite element analysis (FEA) is used to predict system behaviour. Response is directly related to machine design. Generally, as system mass increases, frequency and amplitude of response decreases. As system stiffness increases, frequency of response increases and amplitude of response decreases. It is a given per Newton's Second, in a rotating system, acceleration will always be in phase with force. F=ma where 'F' and 'a' are vectors scaled only by mass. Additionally, velocity and displacement in a rotating system are 90° shifted in phase (Figure 3). However, the phase angle difference between force and displacement can vary. When the phase angle of acceleration and displacement reach 90°, acceleration and velocity become additive and the system reaches a critical state. This critical condition defines the natural (or resonate) frequency. Systems operating at or near the natural frequency are unstable.

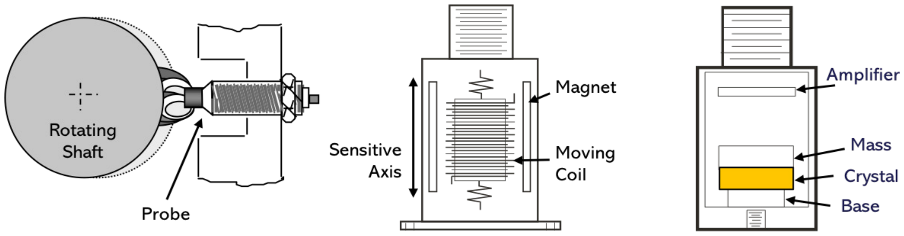

Figure 4. Different types of vibration sensors.

Figure 5. MV motor vibration test using proximity probes.

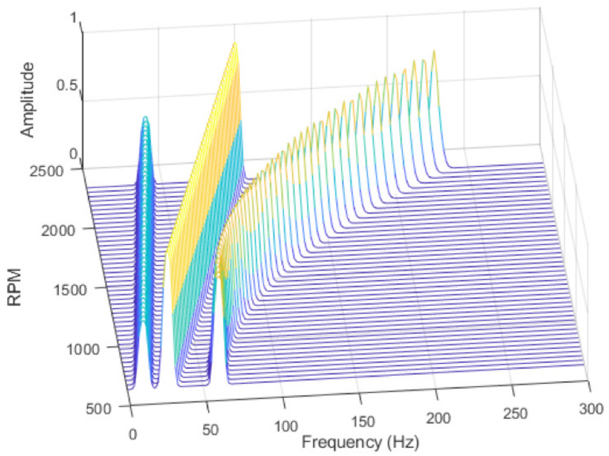

Figure 6. Waterfall plot – spectrum plot over time.

Vibration sensor types and applications

In the world today, there are some exceptional individuals who claim to own a 'calibrated touch'. Experienced field personnel who boldly espouse to possess the ability to identify magnitude and frequency of vibration by simply laying hands on equipment. More remarkable than musical perfect pitch, this is a talent we should all wish to possess. In this regard, the authors of this article are reasonably sceptical and question the precision of this technique. It is suggested, for those of us yet to develop the art of calibrated touch, meters and analysers should be used to determine natural frequency and for diagnosing vibrational anomalies. Three common sensors are used in gathering data for vibrational study; proximity probes, velometers and accelerometers (Figure 4). These probes measure distance, velocity and acceleration respectively. Each convert vibration to an electrical signal calibrated to measure magnitude when used with an accompanying processing unit. In cases of extremely high-frequency vibration, (above 20kHz) ultrasonic sensors may be used in lieu of traditional sensors as the latter may not generate the desired fidelity.

Proximity probes are most often mounted to the bearing housing, but can also be mounted to a stationary object. These probes are extended into the machine and measure position of the shaft varying in time. Velometers and accelerometers mounted to the bearing housing or machine enclosure measure the velocity or acceleration of the body to which they are attached. Proximity probes measure distance by detecting changes in the surface eddy currents as the rotating shaft moves to and away from the probe tip. Inside, velometers have a spring suspended coil around a fixed magnet. As the coil moves between the magnet, a proportional electromotive signal is produced. Accelerometers are solid state devices which create an electrical voltage changing in time as strain is imposed upon the semiconducting components.

Vibration analysis and monitoring

With probes in place and processors calibrated, testing may commence. Tests can identify problems, but are also used to determine the natural frequency of a system. Natural or critical frequencies must be avoided. Operation near a critical frequency can amplify motion whereby rapidly and severely damaging equipment and its supporting structure. Several tests are useful for determining natural frequency. These tests include run-up, coast-down, ring (or hammer test) and intentional imbalance. All tests require an excitation source and sensors to determine the resonate frequencies of the equipment. Vibration meters or analysers are used to derive meaningful results from these tests (Figure 5).

For a reasonable price, vibration meters give good results and show aggregate or average amplitude and frequency of vibration. Analysers are more expensive, but also more useful. Analysers measure magnitude and frequency, but also give access to the frequency domain using the fast Fourier transformation (FFT). FFT is the process of separating vibrational components into narrow integer bins of common frequency. FFT analysers allow the user to view the amplitude of the constituent harmonic frequencies individually. The magnitude of these harmonic components can then be used to determine the root-cause of an anomaly. It can also be used determine critical frequency when used in conjunction with a speed varying run-up or coast-down test and waterfall plots (Figure 6).

Meaningful interpretation of the analysis is the result of collective experience, observation and study by engineers and technicians in a wide variety of industries over a long period of time. Vibrational analysis using the f-domain narrows focus and allows the user to better identify specific problems. For instance, mechanical imbalance appears at rotational frequency (1X), electro-magnetic forces at (2X). (4X) or (6X) vibrations can be attributed equipment such as fans with an equivalent number of blades. Bearings produce vibration at a frequency proportional to a ratio of the parameters of its rolling elements and gears equal the number of teeth. Tables of characteristic frequencies and likely root-causes are readily available.

Conclusion

Modern LNG facilities are designed to produce as much as 500 million ft^3/d per train. Any interruption in the process will result in heavy financial loss. To protect against this loss, industry best practices, published by the American Petroleum Institute (API) and other certifying organisations worldwide, must be followed. These organisations evaluate occurrences of failure to determine and modify acceptance criteria. It is these criteria which equipment manufacturers must meet to participate in the competition for supply.

Vibration measurement and analysis play a substantial role in the reliability of rotating equipment. From design and manufacture to installation and testing, an understanding of participation in, and cooperation with, industrial vibration standards organisations provides greater safety, higher reliability and increased efficiency to all listening to the song sung by spinning stuff. LNG