TURBOMACHINERY OPERATION AND MAINTENANCE

by

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Turbomachinery is sophisticated and complex in order to economically satisfy the process requirements of the petroleum and petrochemical industries. As a result of this increased sophistication and complexity, it is necessary to continually know the condition of the machinery in order to safeguard against shutdowns, losses, and disasters. Consequently modern techniques of monitoring the condition of the equipment are required and are becoming more commonplace.

It is my objective to tell what is required to adequately monitor the condition of turbomachinery; to tell the analytical requirements to interpret data; and to indicate other uses of the data. The details reflect recent experience at one of our plants.

It is necessary to monitor process variables—for a compressor-inlet pressure and temperature, discharge pressure and temperature, flow rate; for a turbine inlet pressure and temperature, nozzle pressure, stage pressures, exhaust pressure, etc. It is necessary to monitor inlet oil temperature, bearing temperatures, or oil drain temperatures. But of equal or perhaps more importance, it is necessary to monitor rotor vibration and rotor axial position. It is this latter part that I want to talk about.

Until recently it has been adequate to monitor vibration occasionally (once per week) using a hand held vibration meter and noting or recording the vibration amplitude of the various bearing housings. Amplitudes were measured horizontally and vertically normal to the rotor axis and also in line with the rotor axis. This information was sufficient to determine machinery condition, such as balance and alignment, and to indicate any changes. Perhaps this method was adequate because of lower speeds, or because of higher rotor weights (more massive lower speed equipment). Vibration measured with a portable instrument in contact with a bearing housing or compressor casing is less than adequate with today's high speed, lightweight turbomachinery. But rather permanently installed non contacting or inductive probes are used to measure the shaft movement relative to its bearings.

These non contacting probes are electronic devices. The change in output voltage from the probe is proportional to the distance between the probe tip and the shaft. The change in voltage can be indicated or recorded. Non contacting probes are also used to continuously indicate or record axial position of rotors.

Load cells of the strain gage type are used to indicate or record thrust bearing load.

In any event the method of monitoring this equipment has changed drastically for several reasons. There is seldom an operator on the platform where the turbomachinery is installed. The ratio of rotor mass to casing mass is such that the magnitude of vibration felt on the exterior of the equipment is not a sufficient criterion for determining the condition of the rotating part. And so it becomes standard practice with today's modern high speed relatively lightweight turbomachinery to provide means of monitoring this equipment with readout in the control room in order to gain an insight into its condition so that maintenance can be anticipated and the equipment can be shut down when required before extensive damage occurs. (See Figure 1.)

As I am sure you are aware, the design of this monitoring equipment is very crucial. We must ask ourselves, what is the purpose of the instrumentation to be installed? How much information do we really need and how do we interpret the data from the installed instrumentation? Data derived from the monitoring probes can be interpreted only when we have done sufficient analytical work to know the dynamics of the rotor, the rotor mode shapes, and the rotor response to a unit of unbalance at any one of several axial locations. So, in order to make use of the monitored data, it is necessary to mathematically model the rotor system prior to startup, and to experimentally verify the mathematical models, preferably during the shop test of the equipment. (See Figures 2a, b, c, etc.)

The most critical variables, at least at this stage in the technological development of rotor system behaviour, seem to be the bearing or rotor support stiffness in both the x-x and y-y planes and the amount and location of unbalance.

With the foregoing in mind, i.e. having prior knowledge of the necessary data for making analytic comparisons, we can indicate more precisely the instrumentation required. We suggest two radial probes at each shaft end and one axial probe per shaft. A single key phaser per unit (turbine plus compressor) is required.

We have found it best to mount radial probes adjacent to bearings, preferably where the probe is looking at an extension of the bearing journal. In this way runout is reduced to zero or to some minimum. Also bearing journals are generally treated with more care than other exposed surfaces, scratches and other imperfections on the shaft surface are not a part of the indicated data. Axial probes should be mounted close to the thrust bearing in order to minimize thermal expansion.

Arrangements should be made to collect and portray the data in several ways.

1. Vibration amplitudes should be recorded continuously on station instruments. (Figure 3.)

2. Axial positions should be recorded on station instruments. (Figure 4.)

3. Raw signals should be collected on a multichannel tape recorder when unusual or excessive amplitudes occur.

4. Real time analysis is very beneficial in spotting the various frequencies. (Figure 5.)

5. An x-y oscilloscope is invaluable in portraying orbital patterns. (Figures 6a, b, c, etc.)

Each of these ways of portraying data is useful in diagnostic analysis.

I have mentioned the need to mathematically model rotor systems and the need to experimentally verify these models prior to startup. Other useful information is obtained at startup and at variable speed. The critical speeds become apparent so that field data can be compared to and correlated with calculated results. Very seldom does the shaft support (bearing, bearing housing, etc.) have the same stiffness in both x-x and x-y planes. Therefore, different values of critical speed will be observed.

Consistent with my stated objective, I have briefly related the requirements to monitor modern turbomachinery for the purpose of keeping the equipment in operable condition and to prevent undue destruction when trouble occurs.

Some of the phenomena we have seen in our plant and our interpretation of these data are as follows:

We have observed significant amplitude of vibration at subsynchronous frequencies. We have diagnosed the problem as oil whirl (Figure 7). In other cases we believe the subsynchronous vibration results from the interaction of bearings and seals. We have seen thrust loads increase far beyond any anticipated value and to change significantly with an indicated axial rotor movement which we interpret as slip in the gear type couplings. Apparently we experience stick-slip type phenomena in the couplings rather than a continuous sliding between teeth.

Briefly, in the area of maintenance, our maintenance engineers have stated that vibration monitoring has been invaluable in providing timely information to shutdown and a great deal of destruction has been prevented. The day to day data indicates any gradual changes and indicates the possible need for inspection.

(Editor's Note: Illustrative material for the above discussion not available at press time.)