BETA

Machinery Analysis

THE BETA BULLETIN

VOLUME 10 #2

Applied Research for Fun and Profit

The following is a portion of the text of the Keynote Speaker, Dave Schuh, as he opened the 2001 CMVA Annual Meeting and Trade Show held in Edmonton, Alberta in August of this year. Dave is Chairman of the Board of Beta Machinery Analysis, founded in 1967.

......I am going to take this opportunity to try to convince you to increase the emphasis on applied research in your company. Applied research is the best win-win deal you're going to get. Basically, you get profits, stimulation, and fun.

FUN

At Beta Machinery Analysis our second research project was developing a digital acoustical model of pulsation in liquids. The lab apparatus to verify the equations was a triplex plunger pump driven by the P.T.O. of my tractor. The pump discharged into a piping system which we designed to be acoustically resonant at about mid speed when pumping water. All of this was hand built by Beta staff. Imagine Dr. Long cutting 2" pipe threads by hand pipe die. This test apparatus was mounted on the floor of my garage. Visualize the pump clattering away, the howl of the tractor and the snarl of the 5HP charge pump. I'm on the throttle and Dr. Long is watching the scope time domain and spectrum. Dr. Long is calling for another 5 RPM. The pipes are starting to hammer the floor, and as we hit resonance "bang on" the place was just vibrating. Dr. Long had predicted pulsation levels at acoustical resonance so severe that at 300 psi average pressure we would reach vapor pressure in the discharge piping. He was right. His equations stood and we are still using those proven equations today. If that isn't fun for you then you are in the wrong business!

STIMULATION

Beta's need for better ways of measuring, recording and analyzing data led us to develop the DATA-TRAP and RECIP-TRAP. Those were the first in the world and led to a whole industry of data collectors. One of the technical problems was that of EMI. Electromagnetic Interference was driving the digital electronics crazy. Our application was collecting data beside the 40000 volt unshielded secondary spark plug wire on big recip engines. The worst possible job! We called in every known expert in North America to help solve this problem. Tremendous technical challenge! In the end, you could lay the RECIP-TRAP on the secondary wire, and get good data!

PROFITS

For every dollar we invested in Applied Research we got back first of all $0.37 from the government as cash (a cheque, not a tax credit) as well as about $15.00 in increased sales over the 25 year period. Applied research is fun, challenging, stimulating and profitable.

THE PRACTITIONER AND THE RESEARCHER

Successful applied research is a joint effort between the practitioner and the researcher.
The desirable and necessary qualities of each person are usually quite different. Seldom will one person be proficient in all the required skills.
Now we must get two people or two groups with widely different skill sets and points of view to accomplish certain tasks. They are not the same tasks, but these tasks have the same goal.
The continuity and direction of the research is easily derailed because the researcher's and the practitioner's efforts in a project are not simultaneous or synchronous.
Let's look at the sequence of events in a typical applied research project.

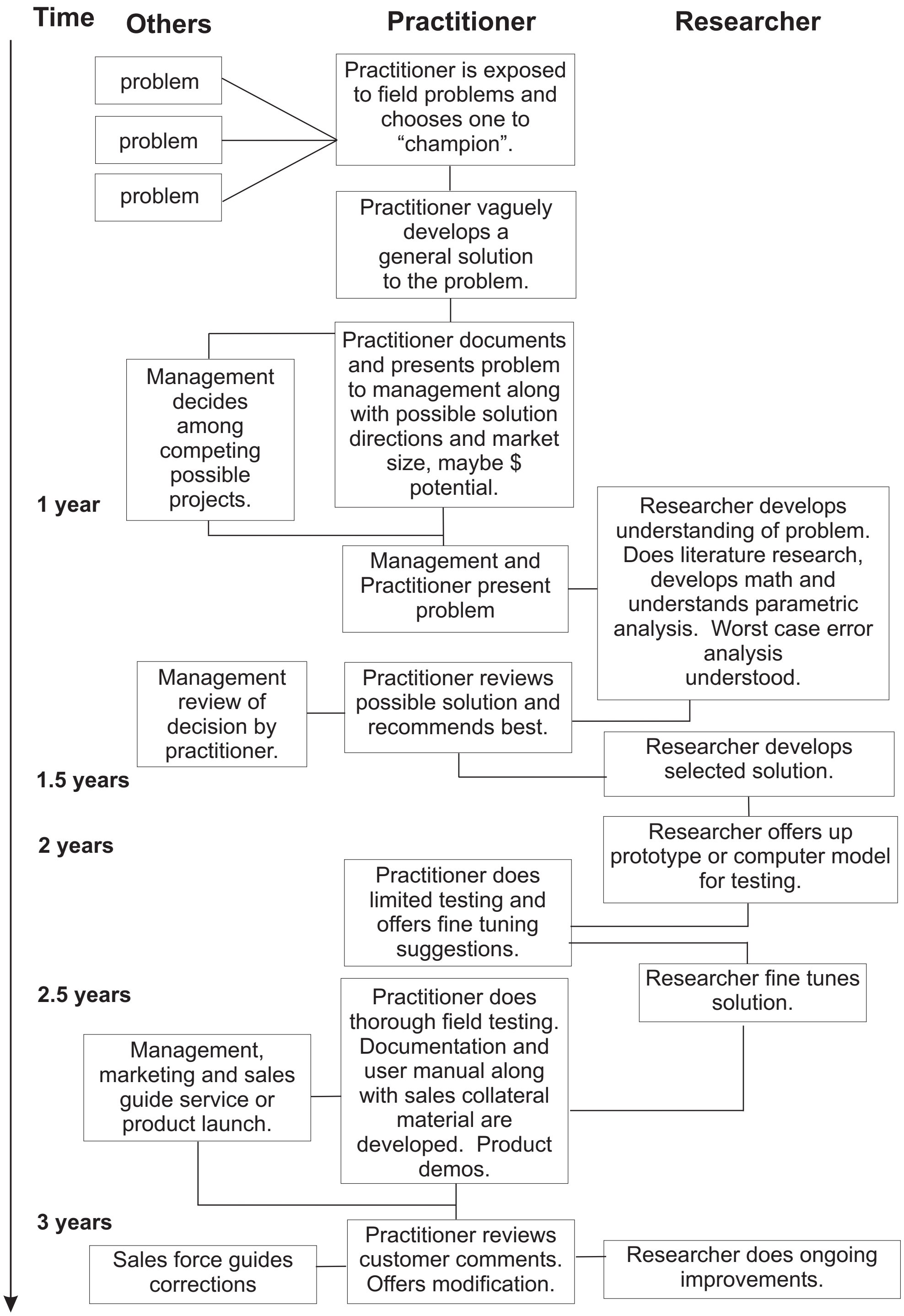
Choice - Choice of project is critical. Successful choice depends on how well management is connected to the front trenches. The criterion is, does the research project solve a "real" problem, one where there will be a commercial demand for the solution developed? The front line trenches are occupied by the practitioner. The practitioner is the source of the "real" problems that become research projects. The awareness, creativity, experience and technical skills of the practitioner are essential ingredients to be able to recognize a possible research project. A vague, very general idea of a possible solution probably exists in his mind at this time.

Decision Time - Practitioner presents the project to management.
- Management selects the one or two of many possibilities based mainly on the practitioner's enthusiasm and presentation skills.

INSIDE:

Applied Research................. 1
GMRC Seminar....................... 2
What's New............................ 2
Torsional Case Study............ 3
LNG Terminal......................... 4

Sequence of Events
Typical Applied Research Project



Research - Now the researcher is on stage, maybe 1 year after the problem was first recognized. The researcher must first develop an understanding of the problem and then conduct a literature search to understand what the rest of the world has been doing in the problem subject. Using a wide variety of skills, the researcher develops a few possible directions the solution may take. This usually requires the breadth and depth of knowledge that Ph. D. graduates offer.

Guidance - The practitioner must provide guidance in choosing between the alternative solutions developed.

Research - Preliminary work by researcher on the chosen solution.

Testing - Practitioner understands the field environment and can design appropriate testing procedures. Product or service instructions to be reviewed by novice users and practitioner.

Marketing- Competitive product or service pricing is probably known by practitioner.
- Competitive advantages are stated by practitioner
- Market segments to be targeted known by practitioner.
- Cooperative customers for first field trials arranged by practitioner.

Sales - Practitioner helps develop and reviews sales material. Practitioner participates in the first product demonstrations.

You want to kick your organization in the rear and get it moving? Applied research will do that and done properly will yield good profits and lots of fun!

What's New?

BMA had a great showing at the Canadian Machinery Vibration Association's (CMVA) 19th Seminar on Machinery Vibration which was held in Edmonton's famous Fantasyland Hotel in West Edmonton Mall. The Seminar had its best attendance ever and membership in the CMVA is at an all time high.

BMA was represented by Dave Schuh, Brian Howes, Bill Eckert, Bryan Fofonoff and John Harvey. Dave was the Keynote speaker. He entertained the participants with a timely speech entitled "The Researcher and the Practitioner." Bill, Bryan and John presented papers which were very well received.

The CMVA is an excellent forum where machinery owners, researchers and vibration consultants get together for an interchange of ideas. For further information on the CMVA, contact Val.Zacharias@cmva.com or phone (403) 208-9618.

Bryan Long, Frank Fifer, and John Harvey will be presenting a two-day workshop for the Gas Machinery Research Council. "Improving the Reliability & Performance of Reciprocating Compressors" will be held November 28 and 29, 2001 at the Marriott Greenspoint Hotel in Houston, Texas.

Anyone who is responsible for the efficient design, operation and/or maintenance of reciprocating compressor systems can benefit from this course. In particular, reliability engineers, project engineers and maintenance supervisors will find the information essential to their career development.

If you have questions on this Course or other GMRC courses, call Marsha Short in the GMRC office at 972-620-4024 or email to mshort@southerngas.org.

A CASE STUDY OF A FLOW-INDUCED TORSIONAL RESONANCE

An evaporator compressor at a processing facility had run successfully for years with a 450 HP variable frequency drive (VFD) electric motor. For production reasons, the unit was modified to a 600 HP VFD. With the larger motor, the coupling failed several times (broken bolts with less than two weeks of run time for each failure).

The compressor is a single stage unit, with a large overhung centrifugal wheel. The suction piping enters the compressor axially, and the discharge piping exits the housing tangentially in the vertical direction. The operating speed range of the unit is from 2600 to 3600 RPM.

Beta Machinery Analysis Ltd., was retained to determine the reasons for the coupling failures. Field measurements of the torsional vibration were conducted with both the 600 and 450 HP drives in place. Measurements included drive torque by strain gauge on the coupling spool piece; current on one phase of the motor input using an inductive pickup and current transformer; lateral vibration in the horizontal and vertical directions on the drive ends of the motor and compressor; and vibration at several points on the inlet piping to the compressor. Startup, loading of the compressor, and loaded steady state operating conditions were examined.

A cascade plot of the torque during that start-up (with the 600 HP motor in place) is shown in Figure 1. Interestingly, the first torsional natural frequency at 42.5 Hz locked in and was present throughout a speed range of 200 to 3600 RPM. As the speed approached 3000 RPM, the compressor surged. While surging, the TNF was excited but the amplitude was highly variable. For much of the time, the instrumentation was overloaded and could not capture readings. During overload, the peak torque had to exceed the full scale range of 13,000 in-lb.

The horizontal vibrations measured at the driven end bearing of both the motor and compressor peaked at twice operating speed. However, there was no component at the torsional natural frequency in the horizontal vibration spectra. As well, the current measured on one of the phases showed only one major component at 1x shaft frequency.

Plant personnel reported that the surge event observed was normal during start-up and loading of this unit.

The compressor was started up and carefully loaded so that there was no surge. The cascade plot of the torque during this event is shown in Figure 2 (from 2500 to 3600 RPM). Again, the torsional natural frequency of 42.5 Hz was present throughout the test. Under load at 3600 RPM, the torque fluctuation at 42.5 Hz was a maximum of 5,080 in-lb pk, and there was moderate variation in amplitude.

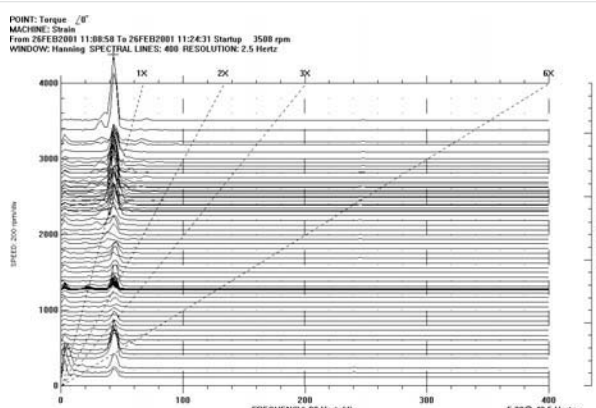


Figure 1

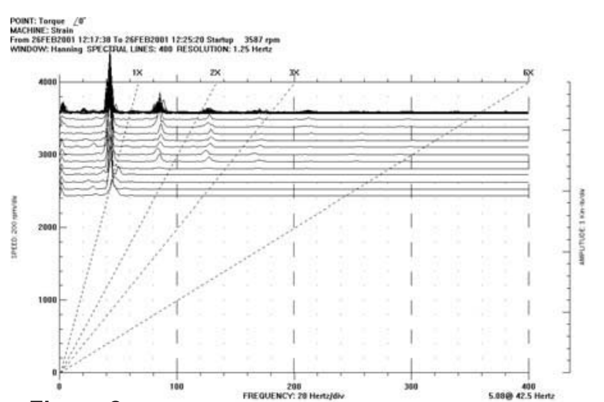


Figure 2

Under surge conditions, the torque fluctuations at the 42.5 Hz were high and the resulting design factor (safety factor with respect to fatigue) on the coupling was much less than one. This indicated that the coupling was definitely sustaining fatigue damage during surge events. We had found the most likely culprit in the coupling failures. Under load without surge the design factor was about 1.0, also not a satisfactory situation. So the question remained what was exciting the torsional natural frequency during normal loaded operation?

From the start-up tests and the trip test it did not appear current fluctuations from the VFD were driving the torsional natural frequency. The only other possible cause seemed to be pressure fluctuations due to some aerodynamic phenomenon.

Vibration measurements were taken on the suction piping and showed small amplitudes at the torsional natural frequency of 42.5 Hz at two locations. These were both downstream of an inspection manway in the suction piping, and upstream of an expansion bellows adjacent to the compressor itself. That vibration component was not found upstream of the manway or downstream of the bellows expansion joint. Unfortunately it was not practical to measure pulsations in the gas stream.

A test was run with the 450 VFD motor in place. The measured torque was substantially different. With the smaller driver, the torsional natural frequency was 64 Hz. This TNF was seen in the cascade of the spectra taken during the ramp up in speed, but the frequency was not locked in over a wide speed range and the magnitude was not excessive.

It was theorized that flow past the manway (see Figure 3) might be responsible for pulsations that could excite the torsional natural frequency under steady state conditions.

Vortex shedding produces pulsations with a broad range of frequencies. However, the center frequency has the highest amplitude and is given by:

$$F = Sn\, U / D$$

where, F = frequency (Hz), Sn = the Strouhal number, U = average flow velocity (ft/s), and D = a characteristic dimension (ft). For flow past a dead leg, like the inspection manway, the Strouhal

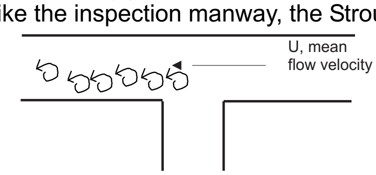


Figure 3

CMS Trunkline LNG Terminal

In June of this year, Bryan Long of BMA presented a course on spectrum analysis for engine/compressor analysts at Trunkline Gas, part of the CMS Energy system. The course was hosted at the company's LNG (liquefied natural gas) terminal near Lake Charles, Louisiana.

At this facility, LNG arrives by tanker from various ports from around the world. The terminal is on a channel 25 miles from open water - this is hurricane territory.

After tugs position the tanker at moorage, the ship's pumps transfer the LNG to three large storage tanks located on the property. Unloading will typically take 12-14 hours. The tanks are heavily insulated to minimize heat leak and consequent boil-off. Since boil-off is inevitable, there is a recovery system that captures all vapors.

Since the LNG is around -260 deg F, piping, vessels and other components are made of stainless steel capable of dealing with these temperatures.

The cold liquid is re-gasified in seven vaporizers. These are heat exchangers in which heated water surrounds the tubes through which the LNG is pumped, emerging in gaseous form. The water is heated by burning a relatively small amount of the gas. The gas produced in the vaporizers then enters the pipeline at high pressure.

A fairly simple process, but quite impressive in operation, the LNG terminal is an important part of the gas supply chain for Trunkline Gas Company. During peak periods, there are about two to three tankers per week being unloaded at the terminal.

Operations at the terminal involve a fair amount of rotating equipment, so this was an excellent location for the training course. The participants measured vibration on various pumps, compressors and blowers. During the learning experience, they found a blower with a significant misalignment problem. Bringing this situation to the attention of the terminal maintenance personnel should result in a reliability benefit as an unexpected bonus.

Case Study, continued....

number varies between 0.3 and 0.6. The manway was approximately 1 ft in diameter and the average flow velocity approximately 100 ft/s. The range of Strouhal or vortex shedding frequencies would then be 30 to 60 Hz, in the approximate range that would excite the torsional natural frequency of the unit.

With the 450 HP motor, the unit torsional natural frequency was on the flank of the vortex shedding frequencies rather than near the center frequency. The magnitude of the pulsation would be lower than near the center frequency, resulting in a lower magnitude torsional response. With the 450 HP motor, the torsional natural frequency was being excited, but the vibration levels were low enough to allow reliable operation.

In this situation, reducing the excitation forces as well as reducing the response of the system was desirable. Reduction of the excitation could be achieved by avoiding surge and by smoothing the flow. The control system should be modified to allow startup without surge; this will have a large positive impact on unit reliability. To reduce excitation of the torsional natural frequency during normal operation, the manway should be modified to accept an internal plug that fills the "dead leg", and creates a smooth inside diameter (see Figure 4). Installation of a soft coupling would introduce extra torsional damping to the system and move the torsional natural frequency somewhat.

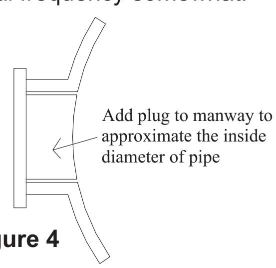


Figure 4

Surge was definitely the largest contributor to the failures of the coupling bolts. However, with the new 600 HP motor and under steady state conditions at full speed, the torsional natural frequency was still being excited. So what was the forcing function? We are confident that current fluctuations from the VFD were not the source. There was only circumstantial evidence that vortex shedding caused by flow past the manway was the forcing function. The calculated Strouhal frequency for vortex shedding and the length of the suction piping were consistent with an acoustic resonance at 42.5 Hz.

Will pressure pulsation in suction piping due to an excited acoustic resonance cause a coincident system torsional natural frequency to respond? It certainly appears so.

Beta Machinery Analysis

Ste. 300, 1615 - 10th Avenue SW
Calgary, AB, Canada T3C 0J7
Phone 403-245-5666
800-561-2382
Fax 403-245-3257

12012 Wickchester, Ste. 105
Houston, TX, USA 77079
Phone 281-920-4441
800-836-4068
Fax 281-920-4442

RR 2, Atrevida Road
Powell River, BC V8A 4Z3
Phone/Fax 604-483-4559

E-mail info@betamachinery.com
www.betamachinery.com