Generator Shaft Stress Testing

Energy

using the LogBook™

Application Note #94

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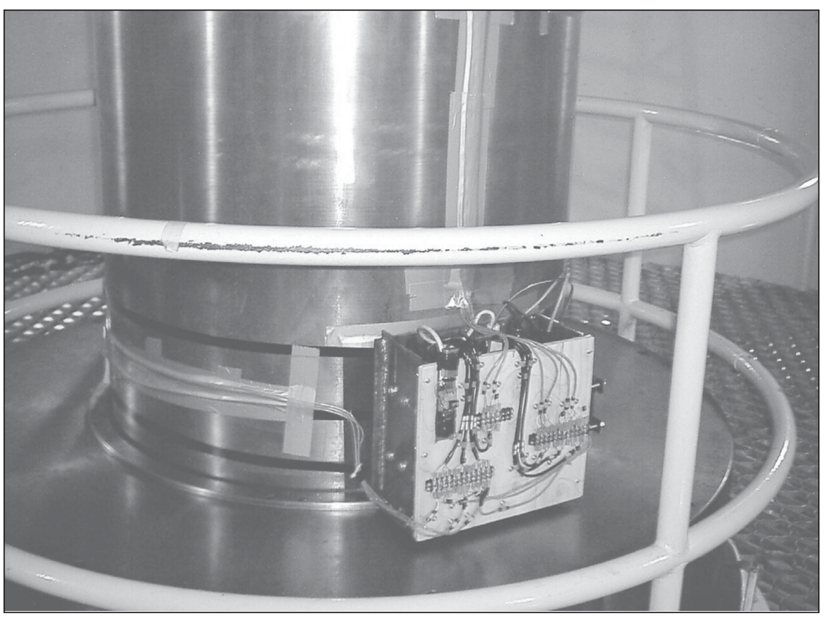
Application Summary

Hydroelectric generators are designed to deliver maximum power output over a predicted life span. However, the output of the generator varies proportionally with the demand placed upon it, which can change from moment to moment or from day to night. The torsional stress on the generator shaft increases with higher demands, and this cycling stress – from low to high and back again – critically affects its fatigue life. Fortunately, the shaft's fatigue life can be calculated quite accurately from measuring these stresses over time.

In addition, a generator shaft often experiences a peak-load increase for a brief time that may exceed its specified rating. In order to ensure that the generators won't fail, the stresses are recorded and analyzed. Another benefit that comes from monitoring shaft stresses is being able to determine the load limits that the generator can sustain by increasing its average capacity. That is, how high can the average operating loads become before the generator suffers from fatigue and outright failure? Determining a maximum tolerable stress can save the expense of installing another generator shaft or replacing the existing unit with one of a higher rating.



An IOtech LogBook, DBK43A strain-gage conditioner, battery power supply, and special terminal board for mounting the bridge completion resistors are all bound neatly in one package and strapped to the generator shaft: The entire data acquisition system is self-contained. The LogBook records the shaft stresses in its 128-Mbyte memory card while rotating at a shaft at speed of 100 rpm. No failures have occurred over three tests in spite of exposing the electronics to about 7 gs.

The Army Corps of Engineers (ACOE) has responsibility for about 75 hydroelectric generating plants around the country, and it is doing exactly this: measuring shaft stresses over a variety of loads and operating conditions to determine the fatigue life and maximum operating capacity of its existing generators.

Potential Solution

The ACOE initially hired two different consulting groups at two different times to make the measurements and analyze the data. They estimated the fatigue life of the shaft and the limit of power they could transmit for a specified number of years. However, Rich Vaughn, Project Coordinator/ Mechanical Engineer, along with his team members, Dan Ramirez, James Boag, and Calvin Hsieh in the Portland District, Oregon, decided that they wanted to perform the tests a little differently, and not have to depend on the schedules of outside vendors to accomplish the task.

IOtech's Solution

Because the generator monitoring instruments they current had were unable to make the measurements, Vaughn's team investigated the data acquisition systems that were available, including those used previously by the consulting engineers. Their conclusion was to purchase an IOtech LogBook™, DBK43A™ strain gage signal conditioner, and laptop computer for the project.

Vaughn's team installed seven strain gage bridges around the generator's shaft to measure axial bending and torsion. The strain gages used for measuring torsion were full bridges, and except for one, the others were half bridges for measuring bending moments. The full bridge used in the bending measurement provided a larger output signal, of course, but did not provide any additional or more accurate data than the half bridges.

In an unusual and novel approach, they strapped the LogBook and its battery power supply to the outside of the generator shaft. As the shaft spun at about 100 rpm during the test, so did the Logbook. This let them run the system and gather data without telemetry equipment or slip rings to deliver the data from the strain gages to the data acquisition system. The LogBook stored data on its 128-Mbyte memory card for up to 45 minutes while exposed to 6 or 7 gs continually and 10 gs intermittently. The total test required about two hours, so the generator was run up and down several times with brief interruptions to download the memory card and replace the batteries prior to another round of data acquisition. The hardware held up perfectly under these conditions and let Vaughn's team collect all the data they needed for analysis.

The stress measurements were recorded while running the generator with a 77-MW load, synchronized to the power grid. Then the machine was cycled between start-up and shutdown with various loads of different power settings to ensure the machine followed a linear behavior, that is, stress proportional to power output. "Sometimes these machines pass through rough zones,' says Vaughn, "So we identify those that might produce worse stress and fatigue, among other issues. We then correlate that data with our known operating history and calculate how many cycles of stress – loading cycles at certain stress levels – were present. We add it up and calculate the life."

"In addition to the stress testing," says Vaughn, "we can see vibration problems when they occur. We also observed that the start-up stress was about half that of the running stress at full power. This can account for a shorter shaft life, so it has to be factored into the fatigue life equation. Hydro generators have to work harder than steam turbines for example, because the steam turbines run at constant speed without cycling on and off."

Measuring rpm was not an issue for the team since the generator runs within 0.1% of the 100 rpm rate, which is synchronized to the power-grid frequency. The generator is typically ramped up to load in 4 to 5 minutes, although it is capable of accelerating to commanded speed within 4 to 5 seconds. Control gates that allow more water to reach the turbine blades increase generator power output, not increasing speed, since it must always remain at 100 rpm.

"We used the eZ-PostView™ software while at the site," said Vaughn, "but imported the data to Mathcad for the report. Mathcad also let us perform some FFT analyses easily, determine whether we had 60 Hz interference, and remove it mathematically when it appeared." Vaughn also adds that they would have been able to accomplish the task with eZ-PostView alone, but felt it was helpful to be able to use nonproprietary software such as MathCad to examine some transient waveforms and oscillations.

"I would summarize the LogBook operation as going really quite well. We thought the LogBook instructions were clean and easy. We have done three complete fatigue life tests to date and anticipate running many more." In addition, although Vaughn's team does not routinely get involved with maintenance issues, they have offered their IOtech equipment and expertise to help that department when they may be able to take advantage of it.

Conclusion

The Army Corps of Engineers maintains about 75 hydro generators around the country to ensure their safety and longevity. Recently, it purchased an IOtech LogBook to measure generator shaft stresses and bending moments. The data are used to calculate fatigue life and the maximum amount of power output the generators are capable of providing over a predictable operating life. The machines typically run for more than 45 years, so accurate measurements are critical. The LogBook provided these data reliably over three tests recently, (even when strapped to the rotating shaft and exposed to 10 gs) and will be used to run many more.

LogBook

The LogBook™ combines on-board intelligence and a large capacity PC-Card removable memory, with the industry's easiest and most powerful data logging software. Its 16-bit, 100-kHz A/D and triggering capabilities make it ideal for collecting high *and* low speed phenomena. A comprehensive array of signal conditioning expansion cards and modules are offered that allow the LogBook to take measurements from virtually any transducer, from thermocouples to accelerometers.

Features

- Operates without a PC at the test site
- 16-bit, 100-kHz analog and digital sampling
- Compact yet expandable architecture can accommodate over 400 channels of analog, digital, and frequency I/O
- Stand-alone nonvolatile storage of over 250 million samples via removable PC-Card memory
- Card swapping and uploading during acquisition allows continuous data acquisition
- Communication with PC via RS-232, parallel port, modem, or by transporting a PC-Card; optional RS-422 interface
- Built-in analog inputs support 14 programmable ranges up to 20V
- Synchronous, mixed signal acquisition of analog, digital, and counter inputs
- Optional modem support provides remote communication
- Optional GPS support (LogBook/360 only) logs location information
- Optional control terminal provides channel inspection, and acquisition queries
- AC or DC powerable

Software

- Includes LogView™ *Out-of-the-Box*™ software for easy setup, calibration, and more; no programming required
- Simple spreadsheet-style interface provides powerful setup features for immediate startup
- Acquisition configurations can be transported to the LogBook via PC-Card, serial port, parallel port, or modem connection
- Provides direct support for a wide variety of transducers
- Includes eZ-PostView™ for post-acquisition data viewing