# TIP 384: In Situ Residual Stress Measurement for Accurate Residual Life Assessment

## Context

Typical residual life assessments of critical welded hydro components seldom incorporate the actual residual stress values of the structures. Typically, either the effect of residual stresses is implicitly considered in the fatigue curves used or values obtained from laboratory samples are used. In every case, a significant level of uncertainty exists, which can affect the accuracy of residual life assessments. For design purposes, these uncertainties can be overcome with proper use of safety factors.

However, when a residual life assessment or failure prediction is needed, it becomes critical to have inputs as accurate as possible, including residual stresses. Therefore, not knowing the residual stresses present in critical areas of components prone to fatigue could significantly affect the reliability and availability of hydropower assets by preventing the reduction of forced outage over the short to long term.

## Description

The project developed methodologies for measuring residual stresses in key hydro components and for the proper incorporation of such measurements in typical residual assessment methods. They will be applicable to all hydro units where components containing residual stresses are subjected to fatigue.

Project tasks included:

1. *Agreement with hydro facility:* Establishment of an agreement with a hydroelectric facility that granted access to a hydro turbine-generator unit for a residual stress measurement campaign.

2. *Literature review:* Review of the literature regarding residual stress measurements and residual life assessment methods and selection of methods to be tested.

3. *Laboratory testing on coupons:* Testing and calibration of selected measurement methods in a laboratory environment.

4. *Shop testing on a prototype runner:* Testing of selected measurement methods on a real turbine runner in shop

5. *Site test preparation:* Preparation and writing of the various procedures in view of the residual stress measurement campaign.

6. *Site test preparation (facility):* Hydroelectric facility preparation in view of the measurement campaign. Close monitoring of activities by the project's team. This task is conducted in parallel with task 5.

7. *Measurement campaign:* Realization of residual stress measurements at the selected hydro turbine-generator unit.

8. *Data analysis*: Analysis of data to validate measurement method.

9. *Development of residual life assessment method:* Development of a methodology for transposing site residual stress measurements into useful inputs for residual life assessments of critical hydro components.

10. *Final report:* Generate the final report detailing the developed methodology, conclusions and lessons learned from the project.

## Benefits

By providing the means to incorporate an input of major impact (residual stresses) in fatigue assessments of components, the reliability of critical hydro components can be better characterized and increased.

The project will help reduce the probability of forced outages, which will contribute to increase the availability of hydro units. This increases the overall efficiency of the generation assets and thus increase revenue for power plant owners and BPA.

## Accomplishments

The main goal of the project was to help the condition assessments of key hydropower components through the measurement of residual stresses. The project's two major objectives were realized: (1) development of an in situ residual stress measurement method for critical hydropower components and (2) development of a methodology for treatment and incorporations of measured residual stresses into residual life assessments.

## Deliverables

The final report details the developed methodology, conclusions and lessons learned from the project.

The project also supplied task reports during the project term.

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**Project Start Date:** October, 2016

**Project End Date:** September, 2018

## Participating Organizations

BPA leveraged the funding of this project with these industry participants:

General Electric Renewable Energy (GE)
Alstom Renewable, USA, LLC
US Bureau of Reclamation (USBR)

## Funding

Total Project Cost: $260,000

BPA Share: $127,000

## For More Information Contact:

**Technology Innovation Office**:
TechnologyInnovation@bpa.gov

## Conclusions

In the context of the hydro industry, the objective of this work was to determine the relevancy of non-destructive Residual Stress Measurement (RSM) devices commercially available. The driving criteria are non-destructive technique (NDT), portability, accuracy, facility and rapidity of use. In addition, a technique is proposed to incorporate measured RS to more accurately predict the effective alternating stress essential in SN-curve based fatigue life assessment of hydro components. A literature review has been formed to update the knowledge of existing techniques. It appears that two techniques have emerged: X-ray diffraction (XRD) and Magnetic Barkhausen Noise (MBN). These two techniques more convenient than the classical hole-drilling technique appear to be the most reliable for in situ (near-) surface RSM. Two corresponding commercially available devices were tested:

1) the XRD device μ-X360 developed by Pulstec; to date the fastest portable XRD technology has a measuring depth range of 6-10 microns for direct stress reading. Two readings per location for residual stress tensor reconstruction.
2) the MBN Rollscan 350, developed by Stresstech; offers scanning capabilities and a measuring depth of approximately 200 microns for magnetic parameter reading. Three readings per location for residual stress tensor reconstruction.

These two devices were tested on a variety of ferromagnetic steel, essentially CA6NM, material components: flat nonwelded coupon, flat welded coupons, tee joint and Francis turbine runner. From these experiences, it appears that the most important items that need to be considered in the planning of an RSM campaign are as follows:

- steel material properties grain size (XRD) and ferromagnetic (MBN);
- site configuration (indoor/outdoor)
- space for RSM device setup;
- component geometry curvature;
- paint/corrosion removal;
- surface finish state;
- measuring locations and directions.

The simultaneous use of the XRD and MBN techniques at site can be a good option to consider in future campaigns. MBN scanning capability is an asset that can be efficiently exploited at site. Indeed, it can be used to rapidly detect hot spots that can be measured afterward with XRD for direct stress reading. That complementarity of MBN and XRD has been demonstrated during the measurement campaign held at Grand Coulee Utility.

MBN belongs to indirect RSM techniques and needs calibration to allow convert magnetic parameter reading into stress reading. Attempt to calibrate MBN from XRD measurements on coupon was not successful due to strong RS non-uniformity observed on measured samples. Eventually the calibration was performed in laboratory based on ASTM standard traction/compression test on flat samples. The calibration was performed on steel material used in modern runner namely CA6NM martensitic steel, welding filler E410NiMo welded FCAW and E410NiMo welded GTAW.

This work was conducted under the financial auspices of Bonneville Power Administration and GE Renewable Energy. USBR supported the project and provided access to Grand Coulee Utility. The technical assistance and service offered by different stakeholders were outstanding and decisive in the successful realization of this project.



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