The Royal Academy of Engineering

Monitoring Vibration Levels in Steam Turbines

RWE npower

Mechanical and Electrical Engineering

Power Industry

npower

INTRODUCTION

RWE npower is a leading integrated UK energy company and is part of the RWE Group, one of Europe's leading utilities. We own and operate a diverse portfolio of power plant, including gas-fired combined cycle gas turbine, oil, and coal fired power stations, along with Combined Heat and Power plants on industrial site that supply both electrical power and heat. RWE npower also has a strong in-house operations and engineering capability that supports our existing assets and develops new power plant. Our retail business, npower, is one of the UK's largest suppliers of electricity and gas.

In the UK RWE is also at the forefront of producing energy through renewable resources. npower renewables leads the UK wind power market and is a leader in hydroelectric generation. It developed the UK's first major off-shore wind farm, North Hoyle, off the North Wales coast, which began operation in 2003.

Through the RWE Power International brand, RWE npower sells specialist services that cover every aspect of owning and operating a power plant, from construction, commissioning, operations and maintenance to eventual decommissioning.

Figure 1: A steam turbine generator unit

SCENARIO

In thermal power plants, energy is extracted from steam under high pressure and at a high temperature. The steam is produced in a boiler or heat recovery steam generator and is routed to a steam turbine where it is partly expanded in a high pressure stage, extracting energy from the steam as it passes through turbine blades. The steam is then returned to the boiler for reheating to improve efficiency, after which it is returned to the turbine to continue expanding and extracting energy in a number of further stages. The steam turbine shaft rotates at 3000 revolutions per minute (rpm) (50 revolutions per second).

Detecting changes in vibration above normal values can highlight that something is changing. Action can be taken before a major failure takes place or the machine has to be taken out of service for investigation. A machine failure can cost £millions to repair and, whilst the machine is not generating electricity, it can cost £hundreds of thousands per day in lost revenue. Monitoring vibration levels is therefore critical to ensure both safety and continued operation.

Figure 2: A low pressure steam turbine that makes one of 5 turbines on a generating unit

At RWE npower, we monitor vibration levels from around 80 large turbine generators around the world, including Indonesia, America, Turkey, Portugal and the UK with a combined output of around 25,000 MW. That is a capacity equal to around half that used by the whole of the UK. Hundreds of individual vibration signals come from transducers on these machines and each must be monitored to ensure they are not changing. Alarms levels are used to aid the analyst highlight potential problem areas and there is a need to set these alarms each time the machine is repaired. Setting the alarms based on statistics enables all alarm levels on a complex machine with many transducers to be calculated in seconds, instead of taking many hours viewing the data and setting the levels manually. Thus, the monitoring process can be carried out more economically. Automation of the alarm setting process can greatly improve the efficiency of the monitoring process.

PROBLEM STATEMENT

In this exemplar, we will calculate an alarm level for turbine generators that generate electricity. The calculation is being carried out with the help of the vibration data set based on previous normal operating history. This will help to estimate how many false alarms may occur in future.

MATHEMATICAL MODEL

For any ungrouped data $x_n, n = 1,2,...,N$, where N is the total number of data available, we can calculate the mean as follows:

$$\text{Mean} = \bar{x} = \frac{\sum_{n=1}^{N} x_n}{N} \quad \dots (1)$$

Also, for this data, we can calculate the standard deviation from mean using the following formula:

$$\text{Standard Deviation} = \sigma = \sqrt{\frac{\sum_{n=1}^{N} (x_n - \bar{x})^2}{N}} \quad \dots (2)$$

Once we calculate the mean and standard deviation of the given data, we can calculate the set limit for alarm using the following empirical formula:

$$\text{Limit} = [\text{Mean} + (4 \times \text{StandardDeviation})] \quad \dots (3)$$

The unit of this alarm limit is μm pk-pk (read as micro meter peak-to-peak). The units of relative shaft vibration are also μm pk-pk, which is the distance between the minimum to maximum value of the signal. For a simple sinusoidal signal $A\sin\omega t$, the μm pk-pk value would be $2A$. These units are those used by the International Standards that give guidance on acceptable levels of vibration.

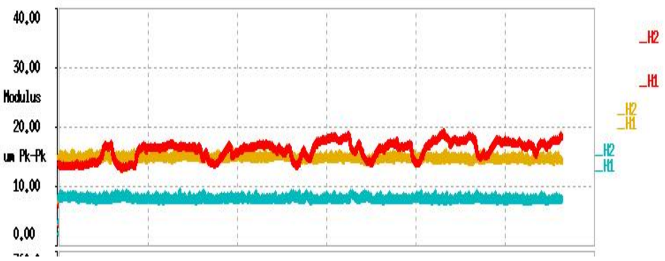

Figure 3: Example of vibration levels for a large steam turbine with the automated higher and lower alarms set on the right hand side

The graph in Figure 3 represents the vibration signals from three different transducers measuring the relative shaft vibration between the pedestal and the shaft (see Figure 3A for a schematic representation of a typical measurement position). This measurement is the movement of the shaft within the oil film of the bearing. The numerical data presented below is a short sample from one of the lines in Figure 3.

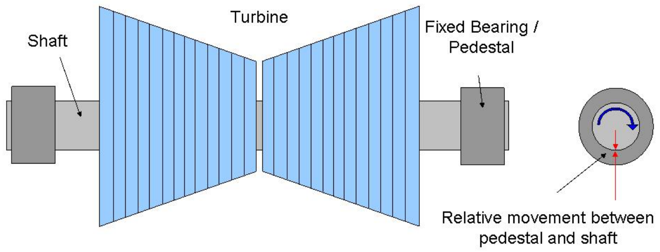

Figure - 3A: Schematic showing a typical location for measuring vibration (μm pk-pk)

CALCULATIONS WITH GIVEN DATA

We have given the following sample data set for vibrations alarm limits (in μm pk-pk):

13.92, 13.91, 13.91, 14.07, 13.75, 13.86, 13.81, 13.79, 13.77, 13.77, 13.87, 13.75, 14.01, 13.63, 13.81, 13.31, 13.34, 13.65, 13.68, 13.75

Using formula given in equation (1) and (2), we get:

Mean= 13.76 μm pk-pk

Standard deviation = 0.18 μm pk-pk

Using these values in equation (3), we get the set alarm limit for this data as:

Alarm Limit=14.5 μm pk-pk

This can be shown in the following graph:

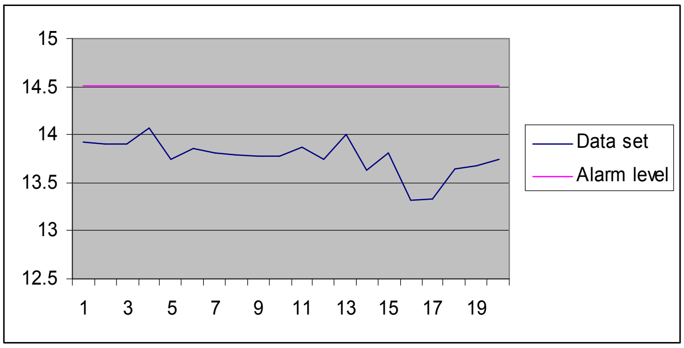

Figure 4: Setting the alarm limit

CONCLUSION

By automatically setting the alarm levels that are derived from normal operating behaviour, it is possible to detect small changes from the norm that could be indicative of the early stages of a developing fault. Such small changes could be missed if the generally higher limits are used that are based on the International Standards.

EXTENSION ACTIVITY – 1:

What is the probability of a false alarm (i.e. data that is greater than the Alarm Limit set but within the expected distribution) and how many of these would be expected?

WHERE TO FIND MORE

1. *Basic Engineering Mathematics*, John Bird, 2007, published by Elsevier Ltd.
2. *Engineering Mathematics*, Fifth Edition, John Bird, 2007, published by Elsevier Ltd.

Gareth – Rotating Plant Dynamics, RWE npower Engineering

He says,

"I joined the Rotating Plant Dynamics team in RWE npower, with a PhD in Vibration and Signal Processing. In my role, I get to analyse and investigate a variety of vibration based problems such as end-winding vibration in generators, as well as monitoring turbine-generator vibration for several power stations. This provides an interesting and highly varied workload as I get to apply my previous skills, as well as continually learning new ones. I consider myself lucky to work alongside globally recognised technical experts, who guide my training and development. Under their stewardship, I have recently become a member on both BSI and ISO Standard committees for Rotating Plant Dynamics and Condition Monitoring."

Information for Teachers

The teachers should have some knowledge of

- Statistics calculation using mean and standard deviation.
- Probability problem for a data set with a normal distribution.

Topics covered from "Mathematics for Engineering"

- Topic 1: Mathematical Models in Engineering
- Topic 4: Functions
- Topic 8: Statistics and Probability

Learning Outcomes

- LO 01: Understand the idea of mathematical modelling
- LO 04: Understand the mathematical structure of a range of functions and be familiar with their graphs
- LO 08: Understand how to describe situations using statistics and use probability as a measure of likelihood
- LO 09: Construct rigorous mathematical arguments and proofs in engineering context
- LO 10: Comprehend translations of common realistic engineering contexts into mathematics

Assessment Criteria

- AC 1.1: State assumptions made in establishing a specific mathematical model
- AC 1.2: Describe and use the modelling cycle
- AC 4.1: Identify and describe functions and their graphs
- AC 8.1: Summarise a set of data
- AC 8.3: Use methods of probability to help solve engineering problems
- AC 9.1: Use precise statements, logical deduction and inference
- AC 9.2: Manipulate mathematical expressions
- AC 9.3: Construct extended arguments to handle substantial problems
- AC 10.1: Read critically and comprehend longer mathematical arguments or examples of applications

Links to other Units of The Advanced Diploma in Engineering

- Unit-1: Investigating Engineering Business and the Environment
- Unit-4: Instrumentation and Control Engineering
- Unit-5: Maintaining Engineering Plant, Equipment and Systems
- Unit-7: Innovative Design and Enterprise
- Unit-8: Mathematical Techniques and Applications for Engineers
- Unit-9: Principles and Application of Engineering Science

Answer to Extension Activities

EA1: Assuming a normal distribution of the data. A confidence limit of 4x Standard Deviations gives a probability of around 99.994%. This is only 6 data points out of 100,000 will be outside the confidence interval. This means that if a set of data consistently shows values greater than the Alarm Limit, the probability is that these reflect real changes in the vibration levels of the turbine and action is required.