March 1, 2013

Background

The gearbox on turbine B010 failed on 2/6/13. The assumption is that the issue was planetary bearing failure. It is on a 35 turbine Gamesa GX7 farm.

All the turbines on this farm were commission in late 2008, with Hansen EH80Z and Fuchs lubricant. Over time the O&M staff has topped off the gearbox with Shell Omala as a new lubricant. It is unclear the extent of top-off on any given turbine.

The customer provided Fluitec Wind with primarily genetic and oil analysis diagnostic data; without operational diagnostic data (i.e. production data, temperature sensor data, etc).

Goal

What Happened: Study the attributes of B010 to better understand its failure characteristics and mode.
Why: Identify metrics and thresholds that signify a "B010-like" failure.
Who is Next: Identify turbines that have breached the identified thresholds.

We take a two-pronged approach: compare the descriptive statistics in parallel with the data mining results, to cross verify observations.

Observations

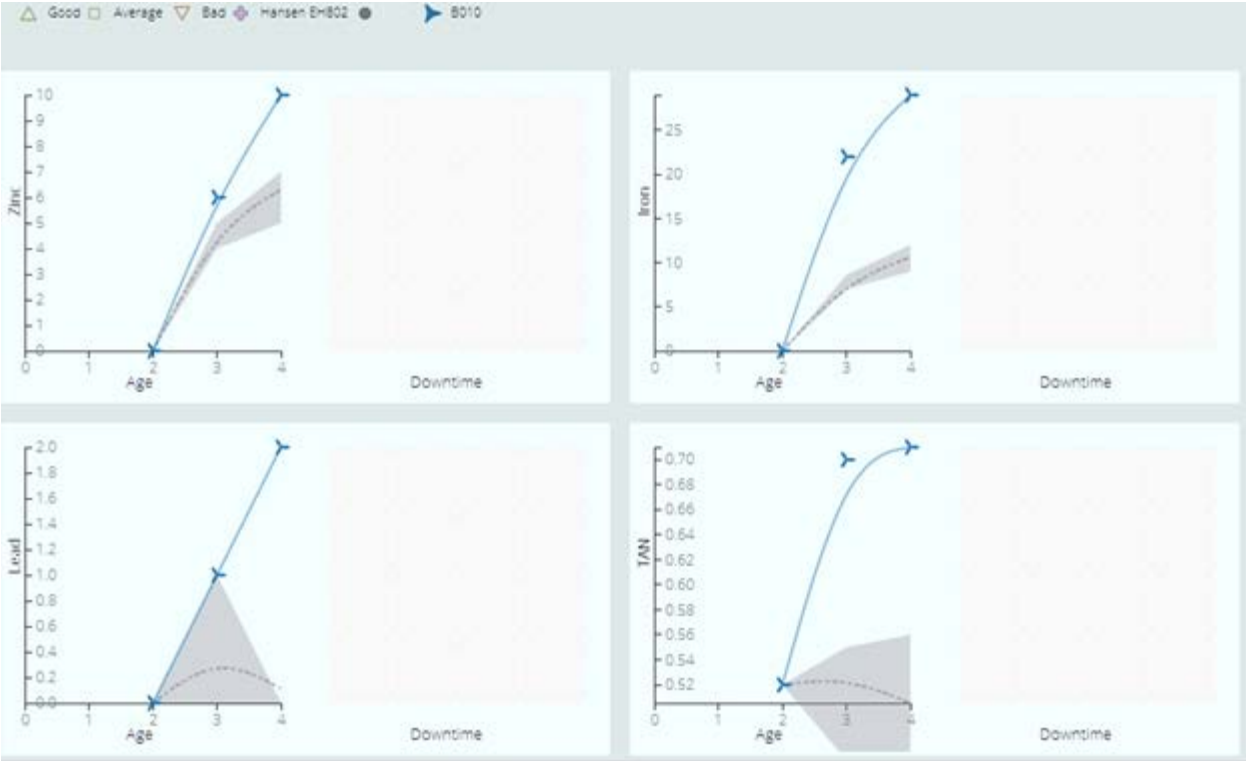
1. We first looked at the raw data to see where we could find descriptive trends. The following is some of the raw oil data for B010 that is available to the customer at **upload.fluitecwind.com**.

LabName	LabNum	SampleDate	Fe	Pb	P	K	Si	Ag	Na	Sn	Zn	H20	TAN	Visc40	ISOA	ISOB	ISOC
NA	NA	9/21/2010	<1	<1	262	<3	1	0.1	<2	<1	<1	105	0.52	323.8	20	18	13
Herguth	V1121644	6/13/2011	22	1	187	<3	6	<0.1	5	<1	6	87	0.7	321.9	16	14	10
Fluitec	847183	5/15/2012	29	2	204	0	8	0	9	0	10	40	0.71	320.1	17	16	12
Fluitec	915394	10/25/2012	34	1	203	0	8	0	9	0	13	60	1.01	322.6	20	18	15
Fluitec	959823	2/21/2013	46	3	274	7	12	0	11	3	18	60	0.73	325.7	18	17	13
Fluitec	959824	2/21/2013	38	2	214	6	9	0	8	5	14	60	0.84	325.7	18	17	13
Fluitec	959825	2/26/2013	46	3	261	7	10	0	8	3	18	70	0.84	326	19	17	14

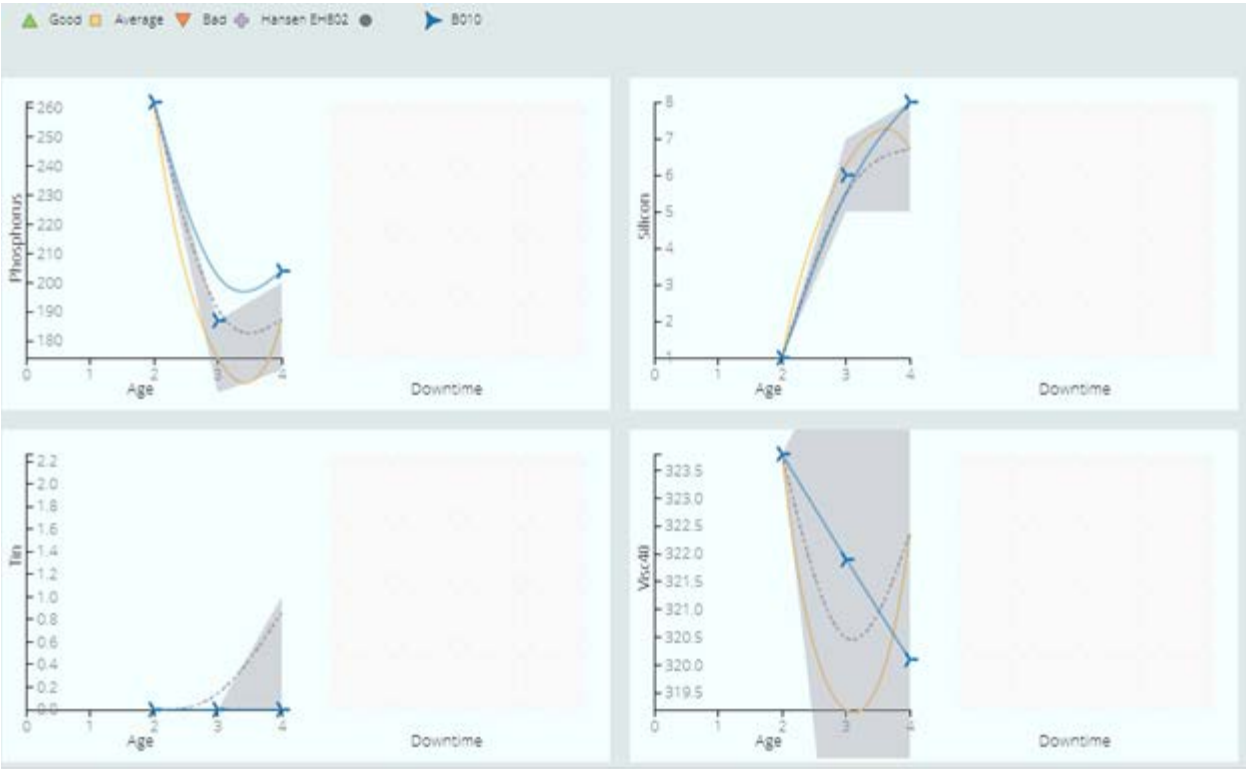
2. We then looked at the attributes that seemed to vary significantly with age to check for abnormality. The highlighted columns above represent those attributes.

   We plotted these attributes for B010 against the overall farm using **Component Analyzer on the TriboAnalytics portal**.

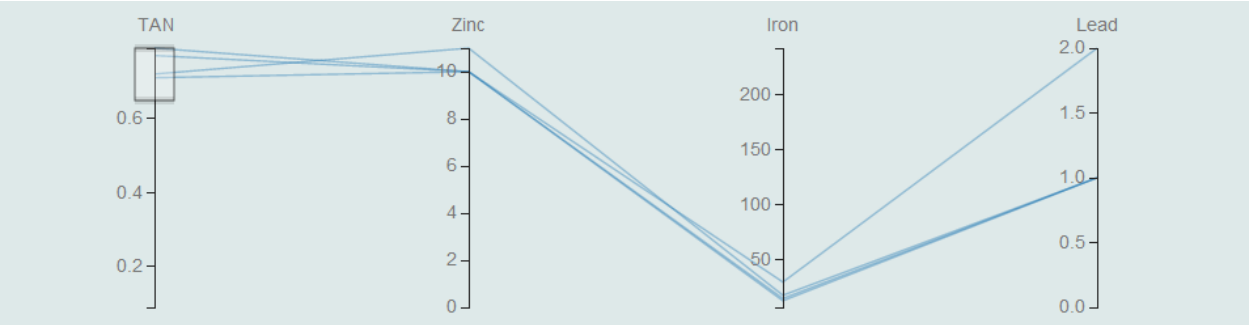
   The following are charts for B010 until 6/1/12, as to capture "predictive metrics". The gray area is the normal range (25th-75th percentile values) for Fuchs oil in a Hansen EH80Z. The first chart shows the attributes (Fe, Pb, TAN, Zn), where B010 values are outliers. One can quickly see that for each attribute B010 is multiple standard deviations away from the mean.



The remaining highlighted variables that varied with age show negligible deviation from the normal.

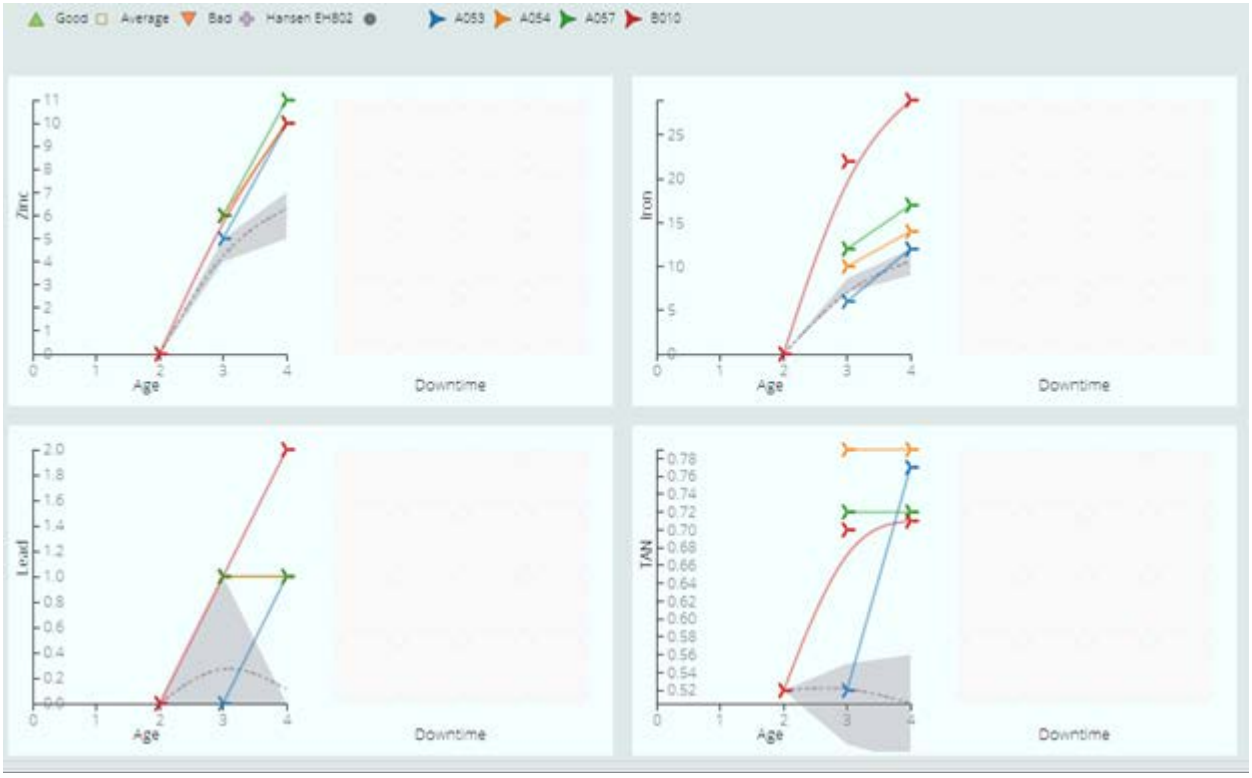


3. We then want to find what other turbines share B010's outlier attributes: TAN, Zn, Fe, Pb. We utilize the **Parallel Coordinates function on the TriboAnalytics portal**.
   The following shows that TAN and Zinc are highly correlated at North Farm: high TAN leads to high Zinc.



   The 4 turbines that fall in the above case of high TAN, high Zinc, High Iron, and High Lead are B010, A057, A054, and A053.

4. We then use **Component Analyzer** to plot these 4 turbines on the same charts to understand how they trend.



   It appears that these turbines suffer from similar dynamics.

5. Based on descriptive statistics we were able to identify outlier metrics prior to B010 failing, in addition what turbines suffer from similar trends; we now take a data mining approach to see whether this heuristic analyses match with the machine model.

   Taking into account the genetic and diagnostic data of each turbine in our database we are able to define similar turbines. We use a method called **log-likelihood as the similarity metric** and then normalize the outputs. This is within the **Similarity Tool on the TriboAnalytics portal**. B010 had the following similarity set (only the Operator's turbines are listed):

Wtg	SampleId	Score	Rank
A057	15381	1	1
A057	15405	0.491991111	21
A053	15401	0.475907012	22
A054	15352	0.471992402	24
A053	15351	0.427361399	31
A054	15402	0.395579181	39

   Score is a normalized representation of how similar a sample is to B010. The average score of the 12,000 samples was 0.012, or 1.2% similar.

   What this means is that out of ~12000 samples, A057 had the #1 & #21 most similar samples to B010.

   The first A057 sample is relatively a 100% match (it is the most similar to B010 out of 12000 peers); the first A053 sample is nearly 50% identical to B010. Therefore each of the turbines listed above has high similarity to B010, and is possibly suffering from the same issue that caused B010 to fail. Moreover these are the same turbines flagged by the heuristic analysis.

   The descriptive statistic results match the data mining models.

<u>Expert Hypotheses</u>

The above allows Fluitec Wind's experts to create hypotheses as the basis of root cause analysis. What we find are specific attributes that are outliers for B010:

- *Lead* could be present in the bearing babbitts that are wearing
- *Iron* could be present in the gears that are wearing
- *TAN* could be higher due to incompatibility with an oil, addition of an acidic additive such as Zinc, or increasing as a function of age.
- *Zinc* increasing is either because of wear of a Zinc alloy or addition of a new additive package. It could also be that the ICP bandwidth for Zinc overlaps with another metal, and elevated "Zinc" may be picking this up: therefore this could simply be another indication of metal wear.

The above trends suggest the following:

1. TAN and Zinc can suggest that new oil was added and is thus changing the oil properties. We know that Shell Omala is being topped off on an irregular basis. This in itself may be a problem that is precipitating wear.

   a. On the other hand, potentially this change in composition could be a corollary of a different problem: the fact that certain turbines need more of a top off, could be a sign of a leakage or other variety of failure.
   b. As a note, TAN is an unreliable attribute due to the test method, it has low repeatability.
2. Increased acid number indicates increased carboxyl acid, which correlates to increased viscosity that is seen. This carboxylic acid being corrosive, are perhaps reacting with metal in the system to produce what would appear to be zinc and other metals.

Data Mining Driven Recommendations

1. Keep track of top-offed turbines in a meticulous manner. There may be a correlation to top-off and increased likelihood to fail.
2. Within the **Query Wizard of TriboAnalytics** set values to avoid B010 like failure:
   Fe > 20ppm AND Pb > 1ppm AND TAN > 0.7 AND Zinc > 10ppm
3. **A057, A054, and A053** have similar critical attributes to B010. They should be closely monitored: potentially a **borescopy** should be conducted on these turbines.

Afterword

The customer took our recommendations and started to closely monitor A057, A054, and A053. It was shortly seen by the customer that A057 had unique vibration profiles, and that perhaps the high speed stage had indications that looked like an early stage failure. Coupled with the knowledge that Fluitec provided, the customer scheduled a visit to the turbine to conduct a borescopy and replaced the high speed stage. They intend to conduct a borescopy on the A054 and A053 next.

Without Fluitec Wind's tool, the customer would not have been preventively notified of failures. This unique analysis preempted an equivalent failure of $250,000, with an up-tower repair of $20,000. The use of big data analytics with oil analysis provided a more predictive tool than the customer previously thought possible.