

## Cumulative Impulse

Cumulative Impulse is a set of measurements that detect and trend the passage of debris particles through the planetary stage of a wind turbine gearbox.

The planetary stage of a wind turbine gearbox has traditionally been a difficult section to monitor using conventional vibration-based techniques. The sun gear, planet gears, and planet bearings have to transmit defect signals through multiple parts and connections to arrive at the outer fixed ring gear where the accelerometer is mounted. This relatively complex signal path can significantly attenuate vibration signals. In addition, during operation, the planets move about the sun, constantly changing the location of the teeth engagement and changing the vibration transmission path. This motion tends to change (modulate) the amplitude of the defect signals.

When damage begins to occur in the planetary stage, whether on the ring gear, the planet gears, the planet bearings, or the sun gear, metallic debris will be shed from these parts. Usually in wind turbines, the planetary stage components are arranged in a vertical plane, so debris shed from one location will tend to fall down into other parts of the planetary stage mesh.

The debris particle causes a vibration impulse on the gearbox casing, followed by a decaying vibration at the gearbox casing natural frequency (Figure 1). When a debris particle falls into the mesh, it can become lodged in the ring, in the sun, or in one of the planets. When a planet moves around the ring or the sun rotates, eventually the gear will move to a position where the debris particle gets trapped between meshing teeth. When this happens, if the debris particle is large enough, it will tend to force apart the two mating gears. This produces an impulse that is transmitted through the entire planetary gear set to the outer ring gear. The ring gear transmits the impulse directly to the outer case of the gearbox where the planetary stage accelerometer is mounted. The result is an impulse of the gearbox casing followed by a decaying vibration at the structural natural frequency.

This characteristic impulse-response signal is detected by the 3701 monitor and is reported as three variables. The monitor studies the planetary accelerometer waveform in real time, looking for impulse response events. When it finds one, it checks to see if it is above a detection threshold; if it is, it increments a counter, measures the amplitude of the impulse, and calculates the number of impulse events that have occurred in the past hour.

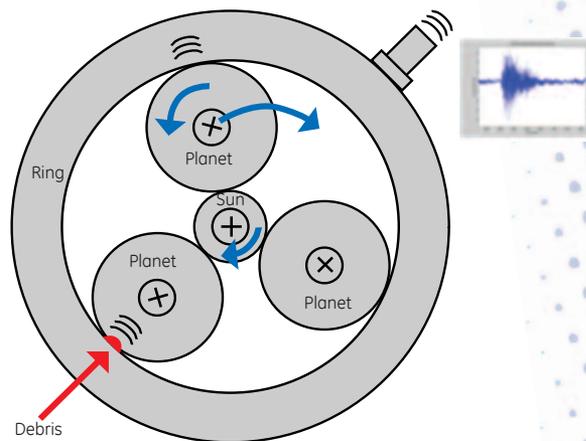


Figure 1. Planetary gear arrangement showing debris that causes a detectable impulse vibration.



impulse, and calculates the number of impulse events that have occurred in the past hour. The monitor reports this information in three variables: Cumulative Impulse Count, Cumulative Impulse Energy, and Cumulative Impulse Rate.

- **Cumulative Impulse Count** is the most fundamental of the measurements. Each time a new impulse is detected, the count is increased by one. Trending this measure over time reveals how many particles above the detection threshold have appeared in the planetary stage mesh. On this trend line, an area of steeper slope indicates that a relatively large number of debris particles were detected in a relatively short time. Shallow slopes indicate periods of relatively low debris particle detection. As the planetary stage progresses toward failure, the number of debris particle detections should increase more rapidly.
- **Cumulative Impulse Energy** is a measure of both the number and the amplitude of the accelerometer impulse signals. The signal amplitude is related to the size of the particle that has been trapped in the mesh. Larger particles will produce larger impulse amplitudes. These amplitudes are accumulated to produce Cumulative Impulse Energy. When this measure is trended over time, the slope is a measure of both the number and size of particles that have appeared in the planetary mesh. This gives us an idea of how bad the damage is in the planetary stage. Like the previous variable, a steep slope indicates a period of frequent and/or large particles, while a shallow slope indicates a period of relatively infrequent and/or small debris particles.
- **Cumulative Impulse Rate** measures the number of impulse events that have occurred over the past hour. It is a plot of the slope of the Cumulative Impulse Count. A high Cumulative Impulse Rate indicates that a relatively large number of debris particles have been detected in the mesh in the past hour. A low rate (or even zero rate) indicates a low (or zero) rate of particle detection. Cumulative Impulse Rate is well suited for alarming so that operators can be alerted to sudden changes in debris particle detection rates.

To reduce the chance of false alarms, the Cumulative Impulse system only detects debris particles that produce a signal above a minimum threshold. Thus, it is possible that relatively small particles will not be counted. In the earliest stages of deterioration, the planetary stage may shed particles too small to be detected but that may be detected by other means, for example, inductive oil debris detectors or filter inspection. As damage progresses, larger particles will be generated, the Cumulative Impulse system detection threshold will be exceeded, and the Cumulative Impulse variables will begin to show changes.

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