TECH corner

Identifying Double Speed >

Case Study: electric resonance and double speed indication during steam turbine startup

BY JUAN CARLOS ISAMU AND M. THEODORE GRESH

Imagine commissioning a new turbine, running it up to speed for the first time, and as you approach speed, the speed abruptly jumps to double the current operating speed. Of course you know that a large steam turbine cannot increase its speed that rapidly, but you now question what the real speed is and how this abrupt speed change happened.

Double speed is not a widely known problem and is even less understood in the turbomachinery industry. This phenomenon is only found on machinery that uses magnetic pickups as the speed sensors. It is a rare issue, but when it does happen it is a high-stress situation for the commissioning and project personnel who have to deal with it.

Sometimes, as the following case shows, the unit passes the factory acceptance test (FAT) without any trouble, making the situation even more confusing and difficult to solve in the field.

Background

A new steam turbine that was driving a wet gas compressor at a coke plant in São José dos Campos, Brazil, was being commissioned. As the unit got close to 3000 rpm, the speed instruments suddenly doubled their value (without a real speed increment) on the electronic governor — the electronic overspeed and the protection device.

The speed pickup system included noncontacting magnetic speed pickups. The target for the speed pickup was a gear. At the FAT, this problem did not occur. The target gear has 30 teeth, but the tooth shape was not the shape recommended by most of the governor vendors.

Two important differences to note are that the interconnecting cables between the speed pickup and the governor were significantly shorter on site than at the FAT. Also, a different make governor was used for the FAT than the one supplied with the turbine.

Figure 1. One of three speed indicators showing the double speed phenomenon (Middle).

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The basic signal shape when "disconnected" from the governor did not change with the speed; only the amplitude did. The conclusion was that the shape of the signal with the sensor disconnected from the governor depends on the gear tooth shape and speed pickup relative dimension only. Thus, the signal distortion (double peak) was related with the associated electrical circuit. An electronic resonance was the root cause.

To confirm the relationship of this problem with an electronic resonance, a signal generator was connected in series with the sensor as shown in Figure 4. A 20% rectangular signal was used due to the second and third high harmonic components and to match the flat of the sensor signal disconnected.

Using a pulse generator (V_{AD}) set to generate a rectangular wave signal 20% duty and 20 Vpp, the signal measured after the speed pickup (V_{BD}) has 33 Vpp. Why can a passive circuit amplify a signal? The answer is only in electric resonance.

Figure 5, left image, is the signal of the speed pickup alone, disconnected from the interconnecting wires. In the right image, the signal is the composition of -1.0 sin (wt) to 0.5 sin (2wt + 10°). Why is the 10°, lower peak of the signal so much smaller than the upper side? Both signals are similar, indicating that the speed pickup signal has a high second harmonic component.

Double speed incident

The sensor specifications are: a) inductance 30 mH (reference only); b) dc resistance 240 Ohms (MAX); c) pole diameter 0.187 in. During testing, the cable capacitance was not measured, but was calculated from the resonance frequency as:

$$C = 1/ \{ L \times (2 p fo)^2 \}$$

$$C = 93.8 \text{ nF}$$

$$Ro = 2 \times SQRT (L/C)$$

$$Ro = 2 \times SQRT (30 \times 10^{-3} \text{ Hy} / 93.8 \times 10^{-9} \text{ F})$$

$$Ro = 1131 \text{ Ohms}$$

$$\xi = R / Ro$$

$$\xi = 240/1131 = 0.21$$

Troubleshooting

The original speed pickups were changed to small pole-tip sensors with the following sensor specifications: a) inductance 210 mH (reference only), seven times higher than original; b) dc resistance 750 Ohms (MAX), three time higher than original; c) pole diameter 0.093 in., half

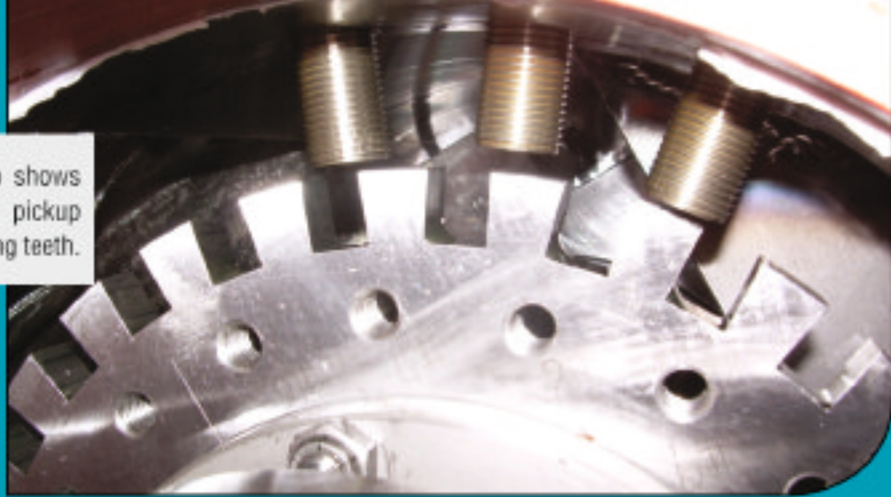

Figure 2. This photo shows the magnetic speed pickup probes and target rotating teeth.

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Figure 3. Signal shape.

of the original. After the change, the speed suddenly changed from 1000 rpm (500 Hz) to 2000 rpm (1000 Hz) => f_o= 1000 Hz. The speed sensor air gap was increased from 40 to 60 mils without changes.

One kOhms resistor was installed in parallel to the governor input (increasing the damping), and the double peaks were eliminated with the double speed indications.

Considering that only the sensor was changed, the capacitance (cable and governor) should remain as calculated in the original configurations,

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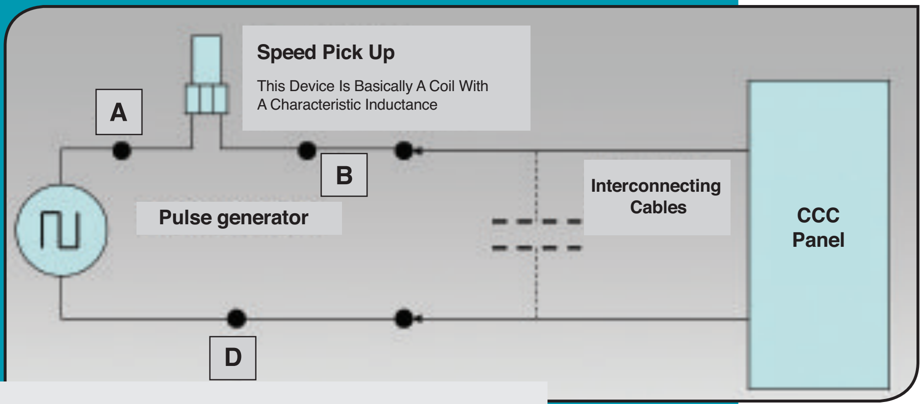

Figure 4. In order to check for something related with an electronic resonance, a signal generator was connected in series with the sensor.

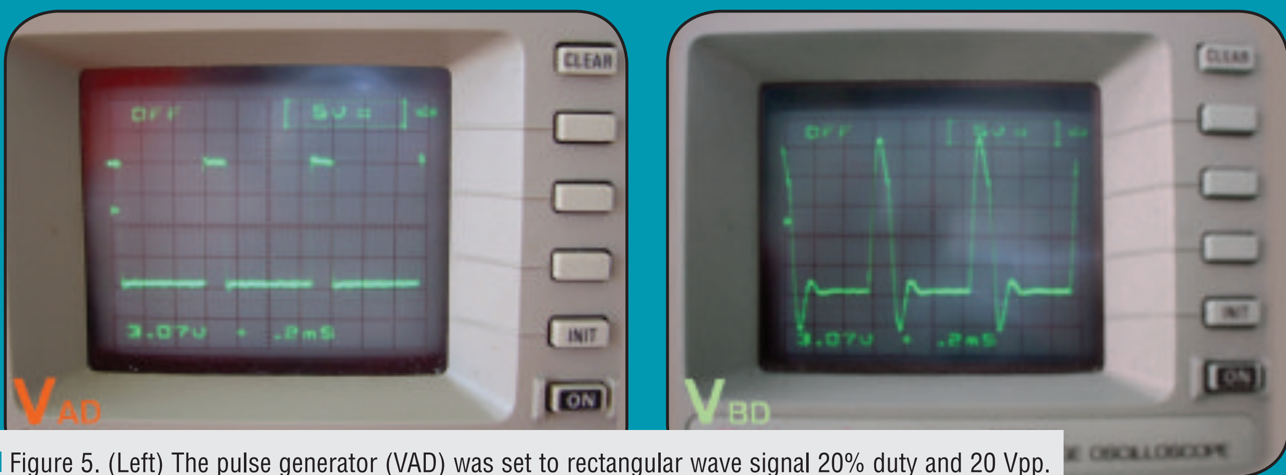

Figure 5. (Left) The pulse generator (VAD) was set to rectangular wave signal 20% duty and 20 Vpp. (Right) The signal measured after the speed pickup (VBD) has 33 Vpp.

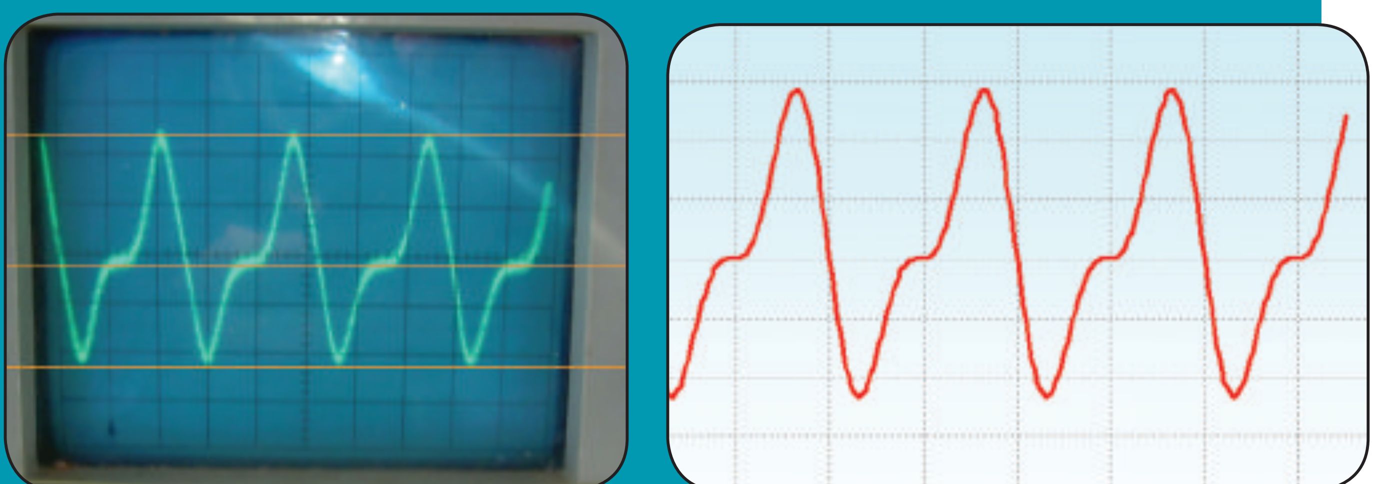

Figure 6. (Left) The waveform signal of the speed pickup alone, disconnected from the interconnecting wires that go to the governor. (Right) The signal as the compositions of -1.0 sin (wt) to 0.5 sin (2wt + 10°).

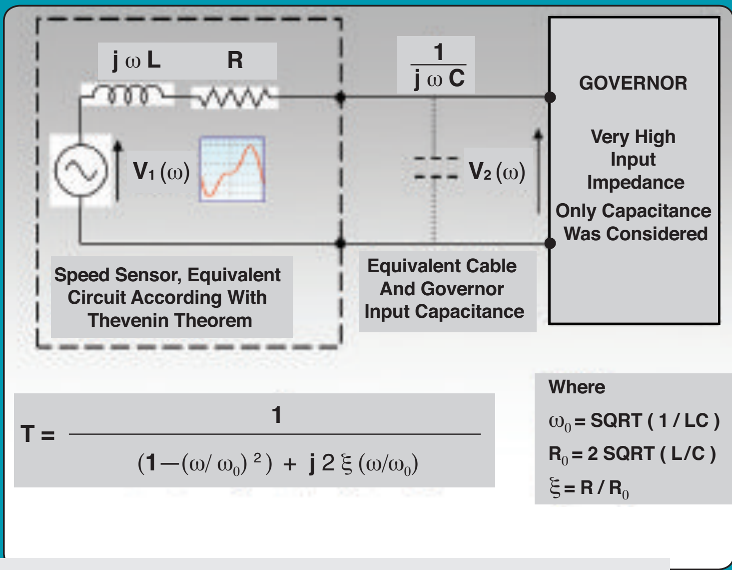

Figure 7. Speed sensor cable and governor electrical circuit.

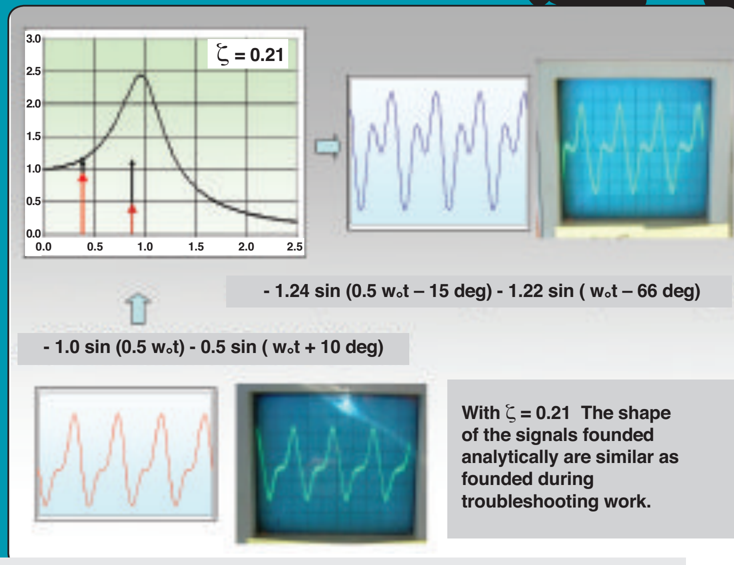

Figure 9. With the damping factor, ζ = to 0.21, the curve shape determined analytically is the same as recorded during operation.

which means 93.8 nF. But the inductance of the pickups was higher at 210 mH.

f_o = 1/{2 p SQRT (L C)}

f_o = 1/{2 p SQRT (210mH 93.8 nF)}
f_o = 1134 Hz

This frequency is compatible with what was actually found during the troubleshooting, reinforcing the idea of an electrical resonance. The inductance increment shifted the resonance frequency to lower values.

R_o = 2 SQRT (L/C) = 2992 Ohms
ξ = 750 / 2922 = 0.26
With ξ at 0.26, double peaks will occur.

The expressions found are similar as the original case (without the resistor in parallel), but the transfer function is attenuated by 1/(1+x) factor. This implies that x should be as low as possible. Also, the resonance frequency is shifted to slightly higher value by the $(1+x)^{1/2}$ factor. The damping factor ξ is more complex, but could be adjusted with R_2

$$\xi = \sqrt{\frac{R_2}{R_1 + R_2}}\left[\frac{R_0}{4R_2} + \frac{R_1}{R_0}\right]$$

Considering

R_1= 750 Ohms
R_0 = 2992 Ohms
R_2 = 1000 Ohms
x = R_1/R_2 = 0.75
ξ = 0.75

This means that with the resistor R_2 added in parallel with the governor, the higher frequency harmonic will be attenuated and the double peak will not occur.

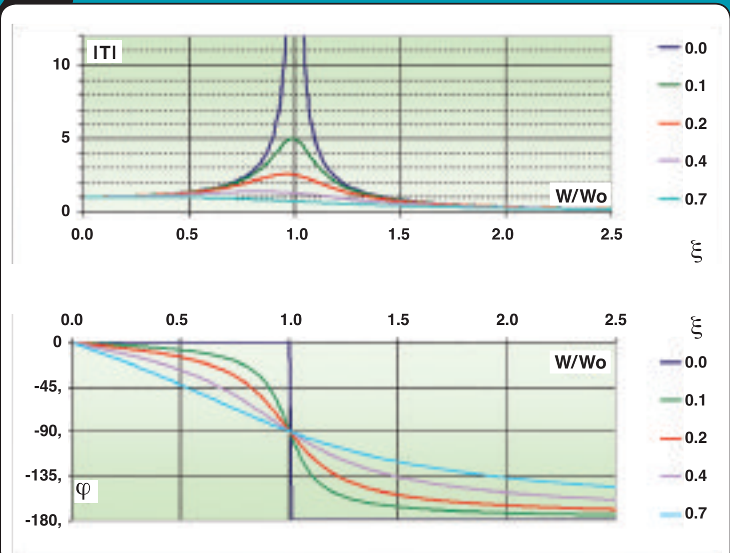

Figure 8. Typical response of a resonant system.

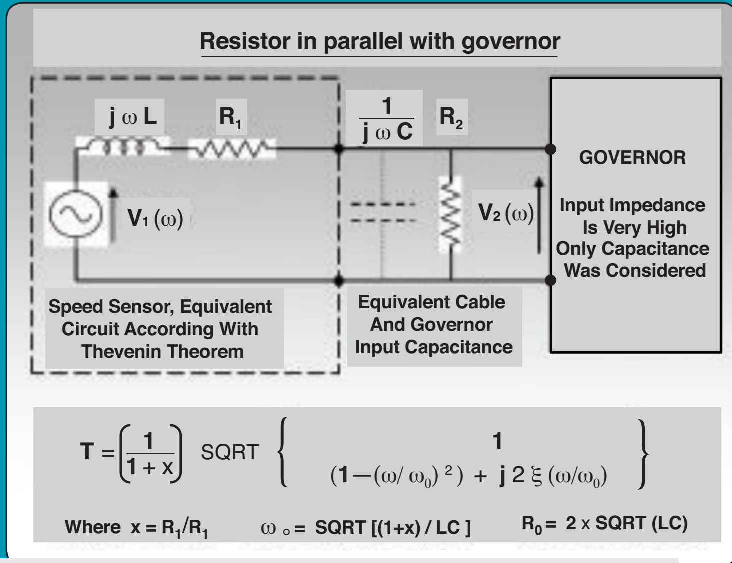

Figure 10. Resistor R2 added in parallel with governor.

Points that support the resonance theory

1. With the original sensor, the actual signal is particularly similar to the analytically found ($\xi = 0.21$).
2. Changing the sensor with a small pole diameter / higher inductance:

a. The double speed indication droops to one-third of the original resonant frequency that matches with a nine times higher inductance, but actually was seven times higher.

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b. The new circuit configurations have a ξ of 0.26, which means an amplification of the second harmonic over the first one, indicating double speed reading.

c. Introducing a 1000 Ohms resistor in parallel, the ξ is increased to 0.75, meaning the second harmonic will be attenuated over the first one. This indicates that double speed will not happen.

Conclusion

Double speed is a problem related with the tooth shape (high harmonic components) and electric resonance, and it requires a two-pronged approach to resolve it.

Mechanical (changing the tooth shape): The tooth shape must be carefully designed in order to have the smallest harmonics component on the signal generated by the pick-ups. As a primary approach, the top area of the tooth should be smaller than the sensor's tip. This will minimize the flat area of the signal which is responsible for the harmonics high amplitude.

Electrical: Introducing a resistor to increase the damping factor (ξ more than 0.4) minimizes the resonance effect. CT2

PRIME MOVERS

Gasmet Technologies

Gasmet Technologies' CEMS II e continuous emissions monitoring system has completed EN 15267-3 testing. The system uses FTIR technology for analyzing low range hydrogen fluoride, low range nitrogen oxide, methane and formaldehyde.

TÜV Rheinland, an inspection and auditing organization, handled the performance tests, which included laboratory and climate chamber analysis, and a six-month field test.

The CEM system has been denoted 'CEMS II e' to highlight the extended range of certified components and its analytical performance. The same improvements also apply to all Gasmet portable FTIR analyzers. German Type Approval and a QAL1 certificate from TÜV are pending for the CEMS II e system. The company is also seeking an update to the British MCERTS certificate.

Wood Group

Wood Group has secured a three-year contract with Shell to deliver industrial services to the St. Fergus gas processing plant in Aberdeenshire and the Mossmorran gas processing plant and Braefoot Bay marine terminal in Fife, Scotland.

Wood Group Industrial Services will provide fabric integrity maintenance and site support under the contract, which has the option to be extended for up to four years.

This is the second contract Wood Group has received from Shell this year. In January, Wood Group Kenny started a three-year contract providing specialist consultancy services for flexible riser integrity management prior to and during operation of Shell Australia's Prelude Floating Liquefied Natural Gas (FLNG) project. Shell said Prelude FLNG, which is under construction, is the world's first FLNG development.

WEG

WEG has acquired Bluffton Motor Works LLC (Bluffton), an electric motor manufacturer with headquarters in Bluffton, Indiana. Founded in 1944, Bluffton specializes in manufacturing fractional electric motors up to 5 hp (3.7 kW), offering a wide range of customized products to customers in the United States. Bluffton headquarters occupies approximately 400,000 sq.ft. (37,161 m^2), and the company employs over 400 people. Net revenue in 2015 was approximately US$64 million.

With over 31,000 employees, WEG is one of the world's largest manufacturers of electric-electronic equipment, having five main businesses: Motors, Automation, Energy, Transmission & Distribution, and Coatings. WEG has manufacturing units in 11 countries and is present in more than 100 countries, servicing all industrial segments, including oil and gas, mining, infrastructure, steel, pulp and paper, renewable energy, among many others.

ACD

Cryogenic turboexpander and pump manufacturer ACD has promoted **Brice Lemaire** to sales manager – European Market. Lemaire will be based out of the company's ACDCryo offices in Switzerland and will lead ACD's efforts to expand business in existing and emerging markets. Brice has been the technical sales engineer at ACD-Cryo for three years.

ACD, LLC manufactures cryogenic pumps and turbo expanders for the alternative fuels, industrial gas and oil industries. The company's product line includes a variety of cryogenic pumps for LNG, high-pressure cylinder/storage filling systems, trailer off-loading, bulk transfer, LNG bunkering operations, and storage tank filling. With over 50 years of experience, ACD offers highly engineered solutions to challenging problems in cryogenic equipment design and operation. ACD is part of the Cryogenic Industries Inc. family of companies, which include Cosmodyne LLC and Cryoquip LLC.