- Bryan Barrington is a 1994 graduate of Texas A&M University and currently works as a Principal Machinery Engineer in LyondellBasell's corporate engineering group. He is responsible for turbomachinery at locations along the Texas Gulf Coast.

Speed Signal Deterioration at High Speeds in Electronic Governor and Trip Systems

40th Turbomachinery Symposium Case Study

Presented by:

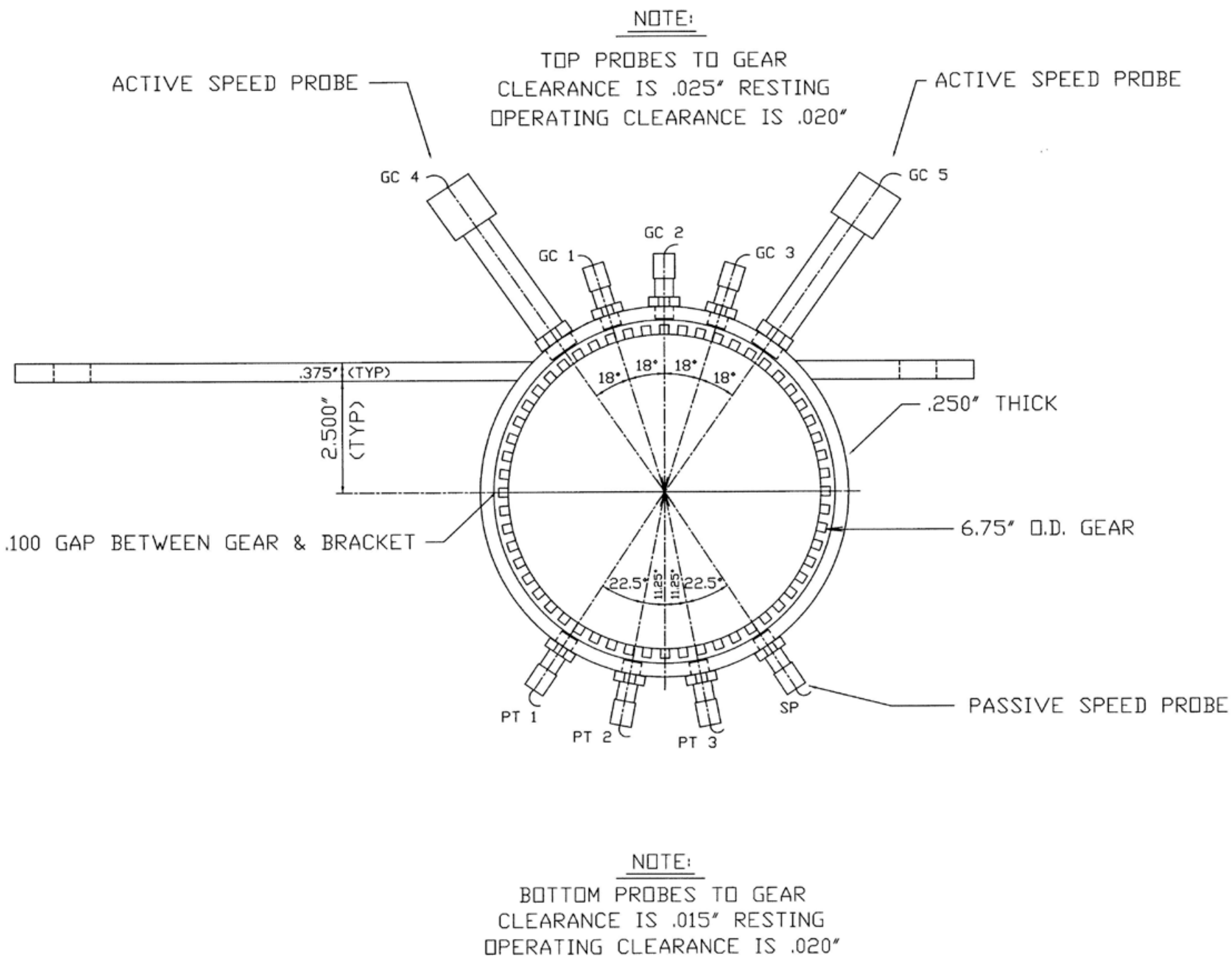
Bryan Barrington
Machinery Engineer
Manufacturing and Engineering Support, The Americas
Lyondell Chemical Company, A LyondellBasell Company

Background

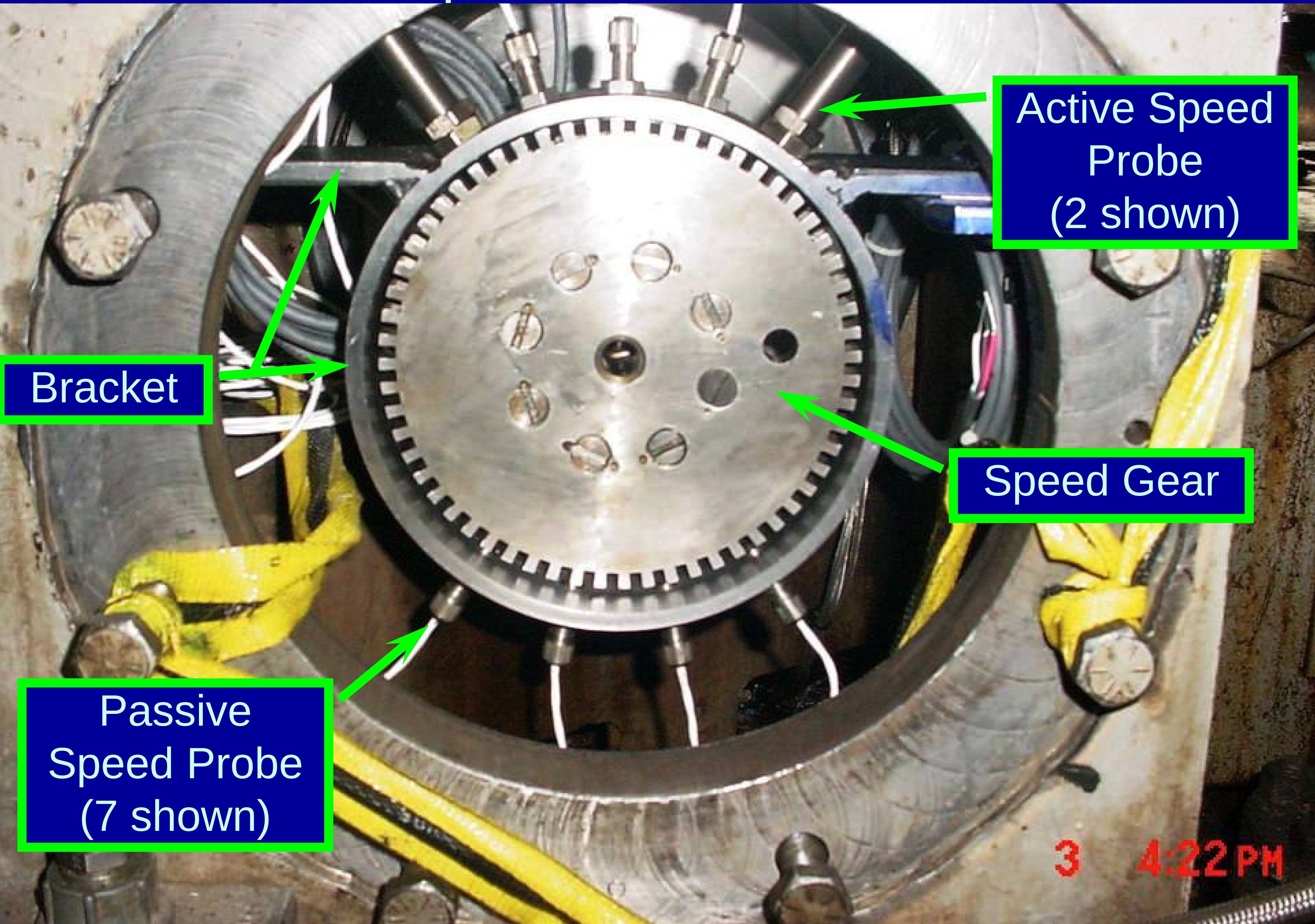
- 9300 hp steam turbine driving a centrifugal compressor at 6100-8100 rpm.
- System retrofit in 2004 to an electronic governor and triple modular redundant overspeed trip system was completed without issue – or so we thought.
- This retrofit used a proven design that had been installed on two larger 4000 rpm steam turbine systems in 2001.

475

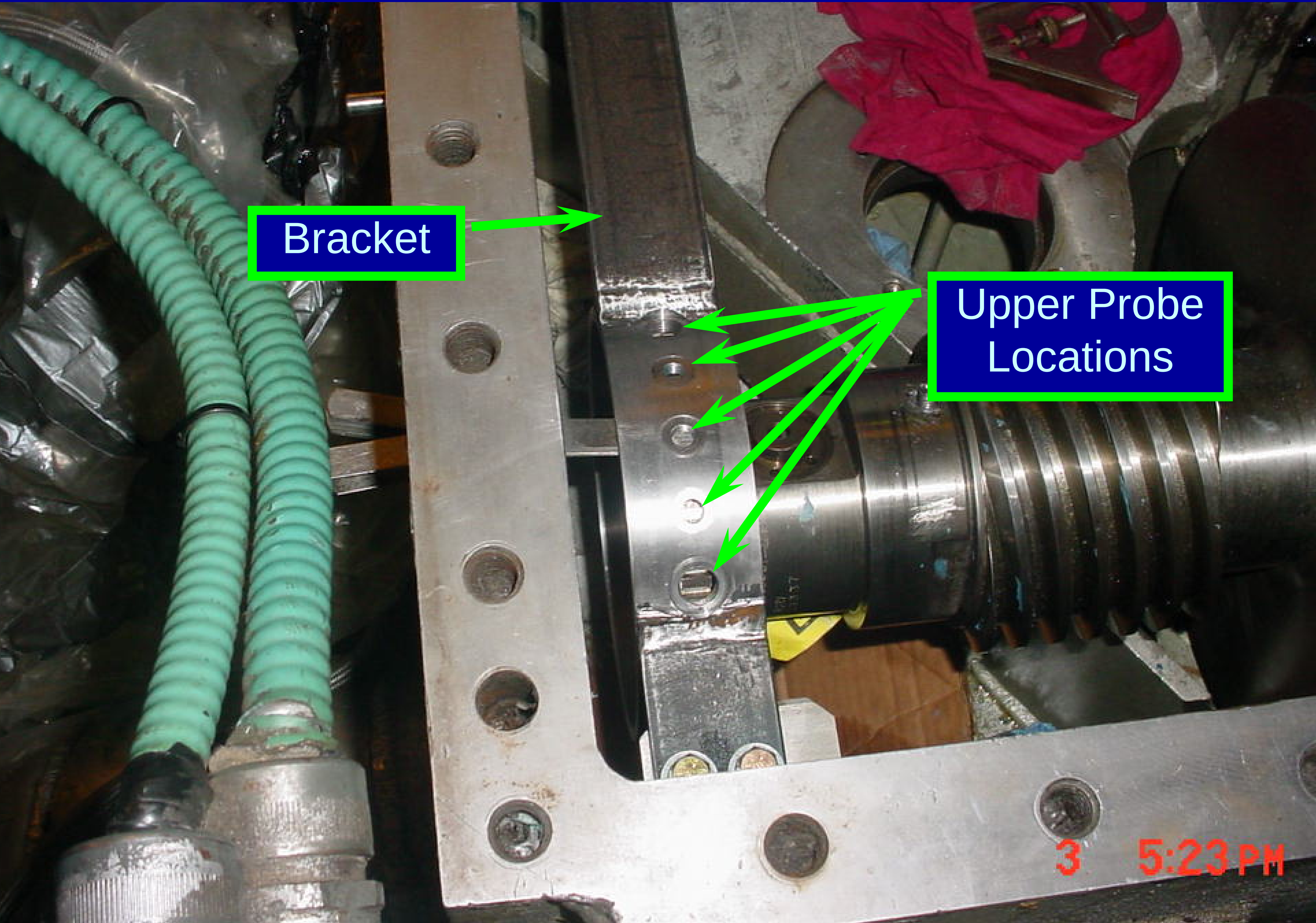
Drawing of Bracket, Speed Gear and Probe Configuration



Axial View of Speed Gear, Probes and Bracket



Plan View of Bracket



Background

- A complete turbine overhaul in 2010 required disassembly of the bracket and removal of the probes.

- Reinstallation was completed using:
  - The same installation procedure,
  - The same bracket and probes, and
  - A new, duplicate speed gear that had been mounted on the spare turbine rotor.

System Characteristics

- There are 6 identical passive probes.
  - Three of the probes send redundant signals to the overspeed trip system.
  - The remaining 3 probes send redundant signals to the governor.

- Input deviation alarms sound if any governor signal is different from the control signal by greater than a prescibed amount.
  - This alarm/condition does not remove the signal from the voting logic.

System Characteristics (cont'd)

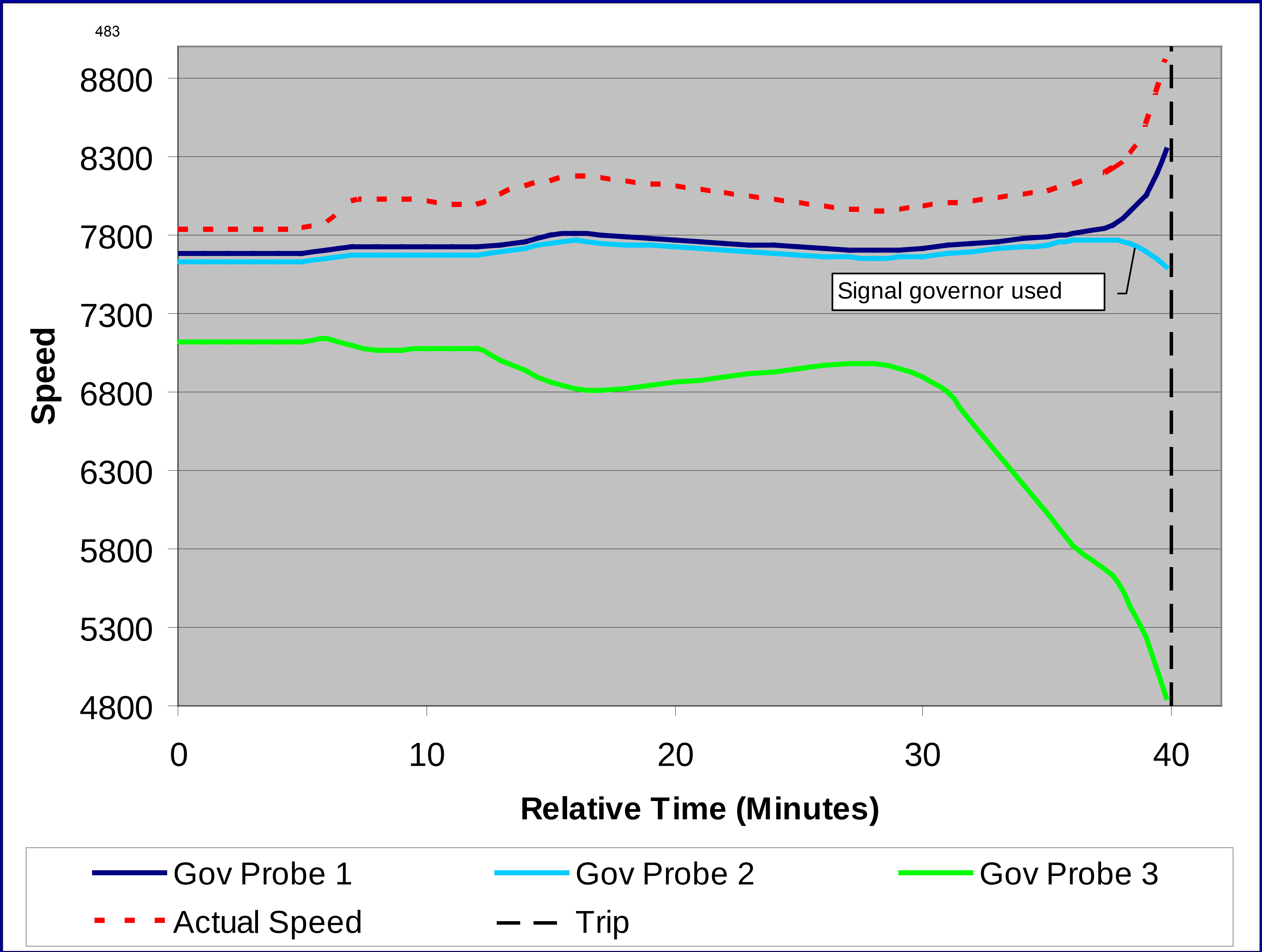
- Voting logic uses the median value for 3 good sensors.
- A signal is determined to be faulty and is taken out of the voting logic only if it falls below a predetermined setpoint.

Problems Appear. . .

- Turbine overspeed testing was the first indication that problems existed.
- Multiple individual probes did not respond correctly at high speeds.
  - First run had 2 probes with issues. These were replaced, which required the wiring of all of the probes to be disconnected and manipulated.
  - Second run had a different probe stop reading. It was replaced.
  - In the final run, the turbine was not brought to overspeed settings as the probe was proved out at the lower speeds. At this point, we also found that the spare probe was no longer functioning.
- The initial assessment was that the probes were old and that their wiring had been affected by heat.

And Disappear . . .

- The turbine was coupled to the compressor and the train was put online.
- The train was shut down 2 days later due to other process problems. It was again restarted without issue.
- Three days later the process required a gradual change in turbine speed . . .



483
8800
8300
7800
7300
6800
6300
5800
5300
4800
Speed
0
10
20
30
40
Relative Time (Minutes)
Signal governor used
Gov Probe 1
Gov Probe 2
Gov Probe 3
Actual Speed
Trip

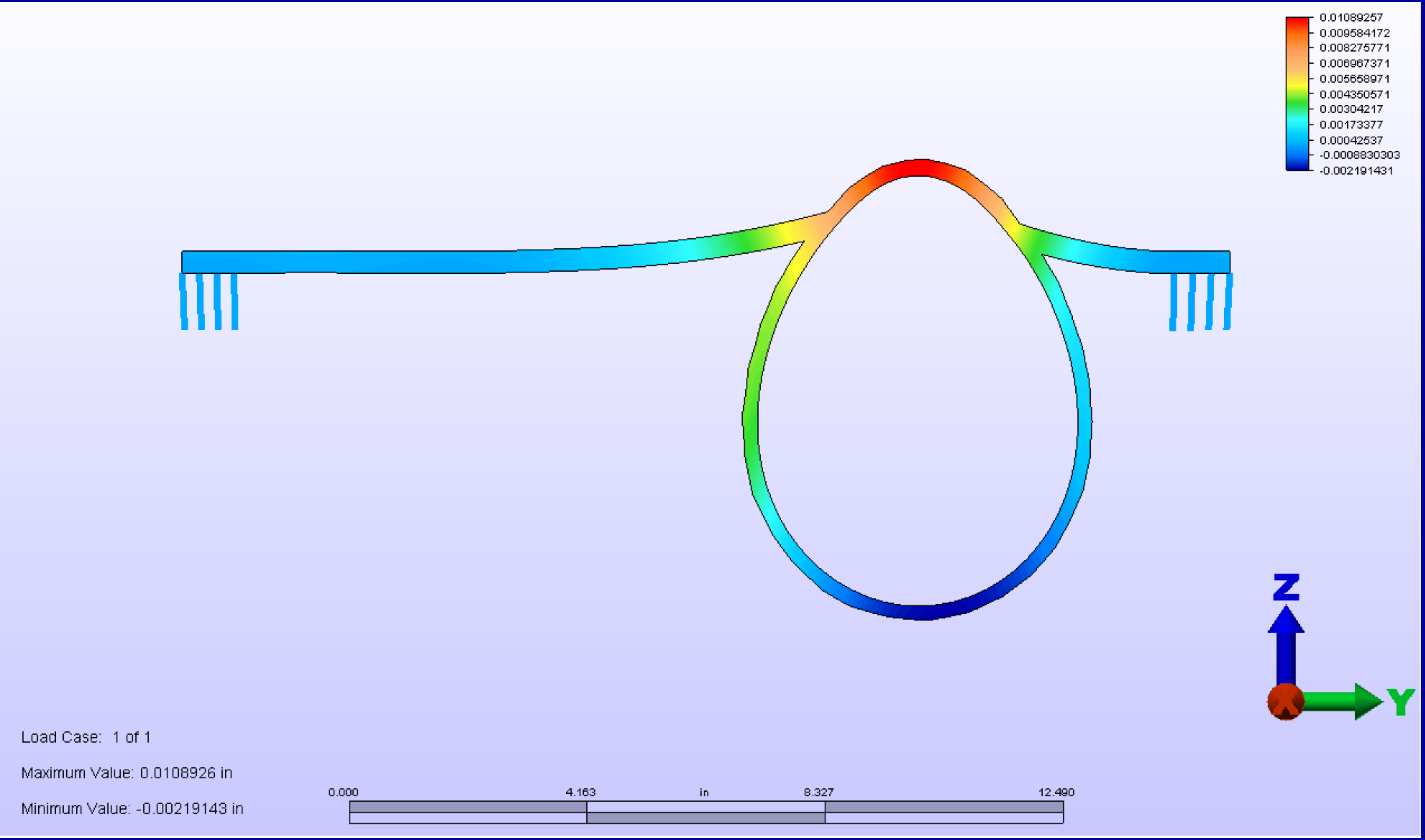
Speed Signal Issues

- Analysis of the probe signal revealed two problems:
  - A reduced voltage output from the probe as measured at the turbine, and
  - A significantly reduced voltage as measured at the input to the governor panel.

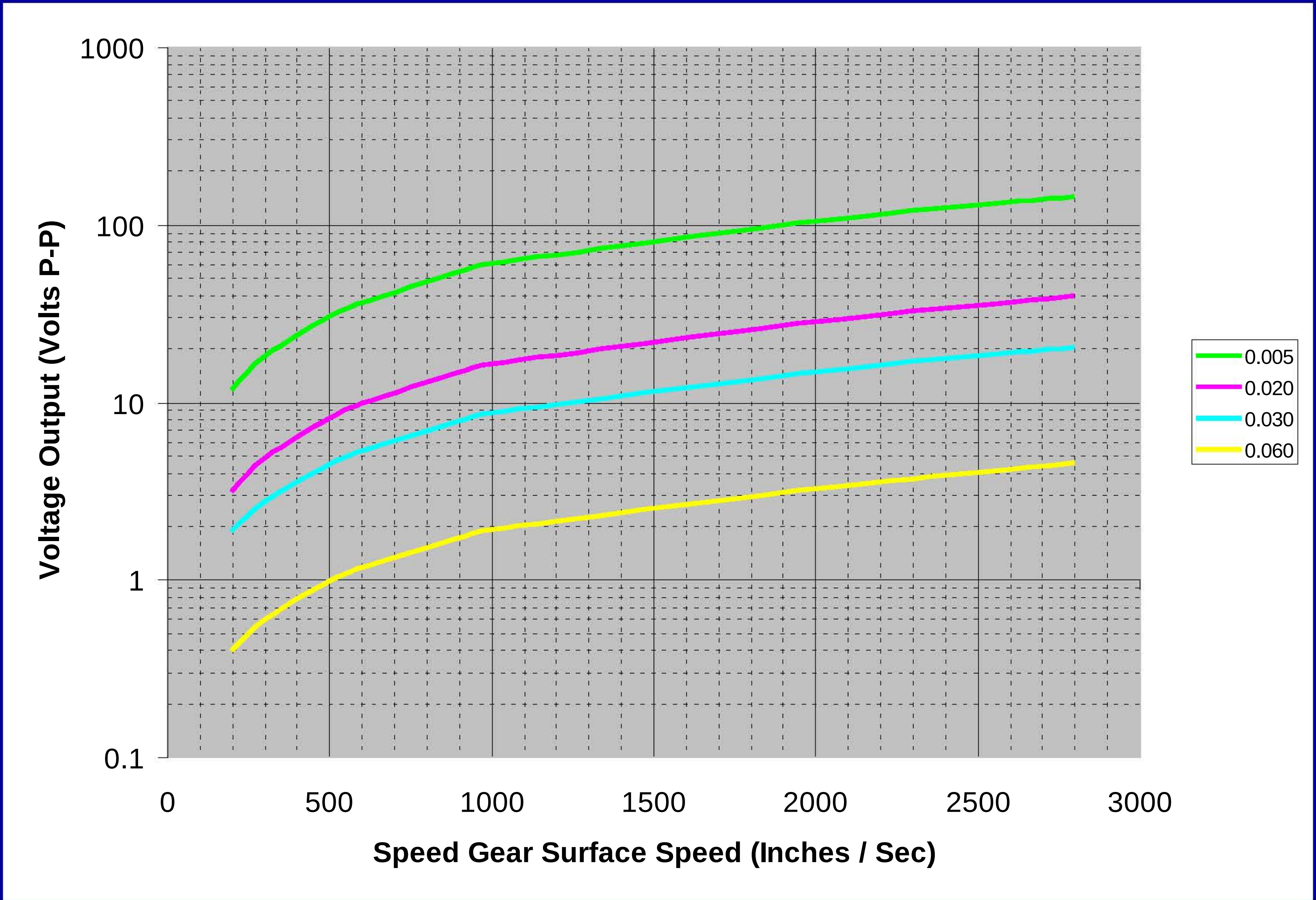
Speed Signal Issues

- Speed probe voltage *generated* is a function of:
  - The surface speed of the target,
  - The geometry of the speed gear, and
  - The distance between the probe and the speed gear (the “gap”).
- How could the gap be incorrect?

Bracket Deformation Due to Thermal Stress



Speed Probe Voltage Output

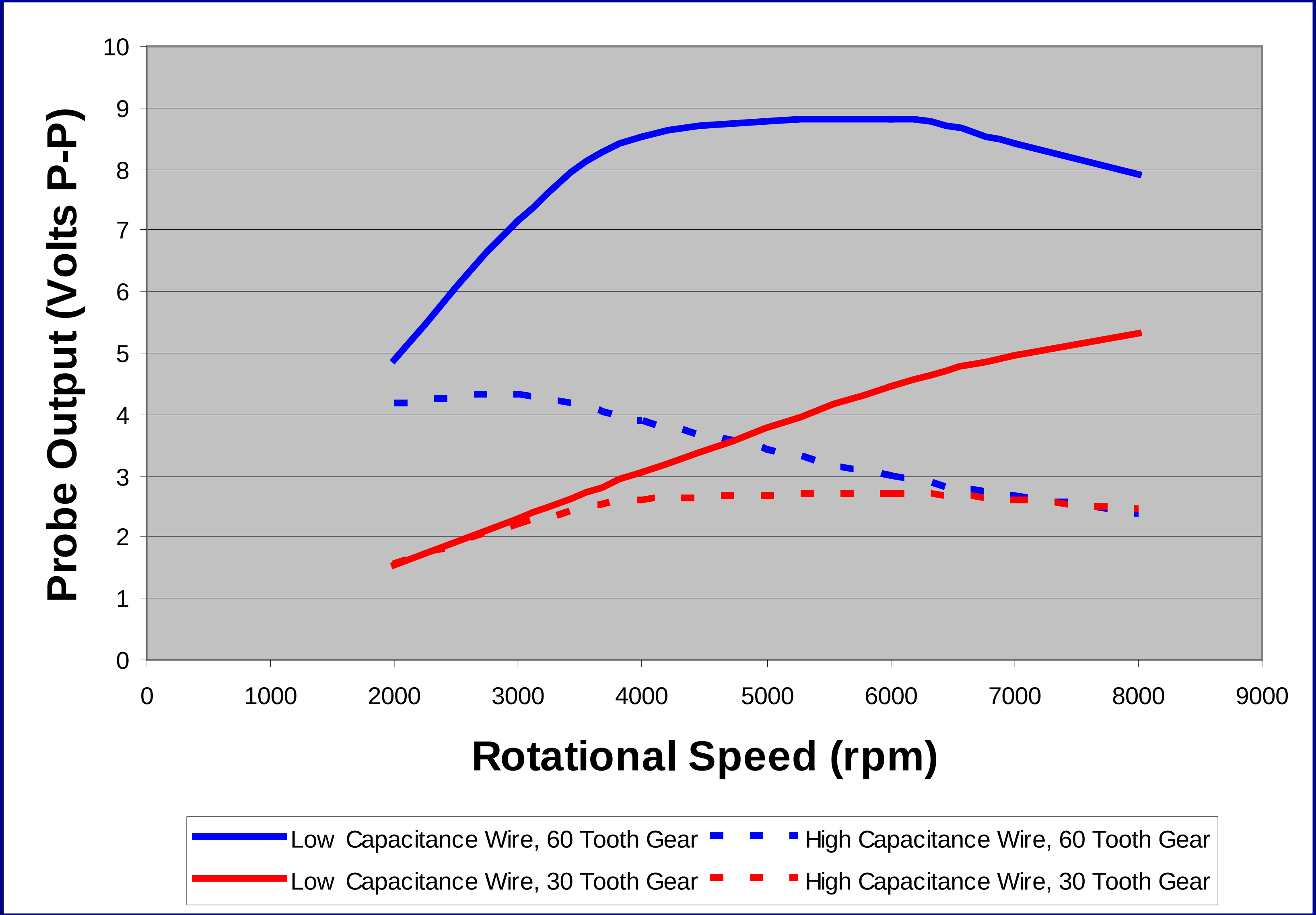


Speed Signal Issues

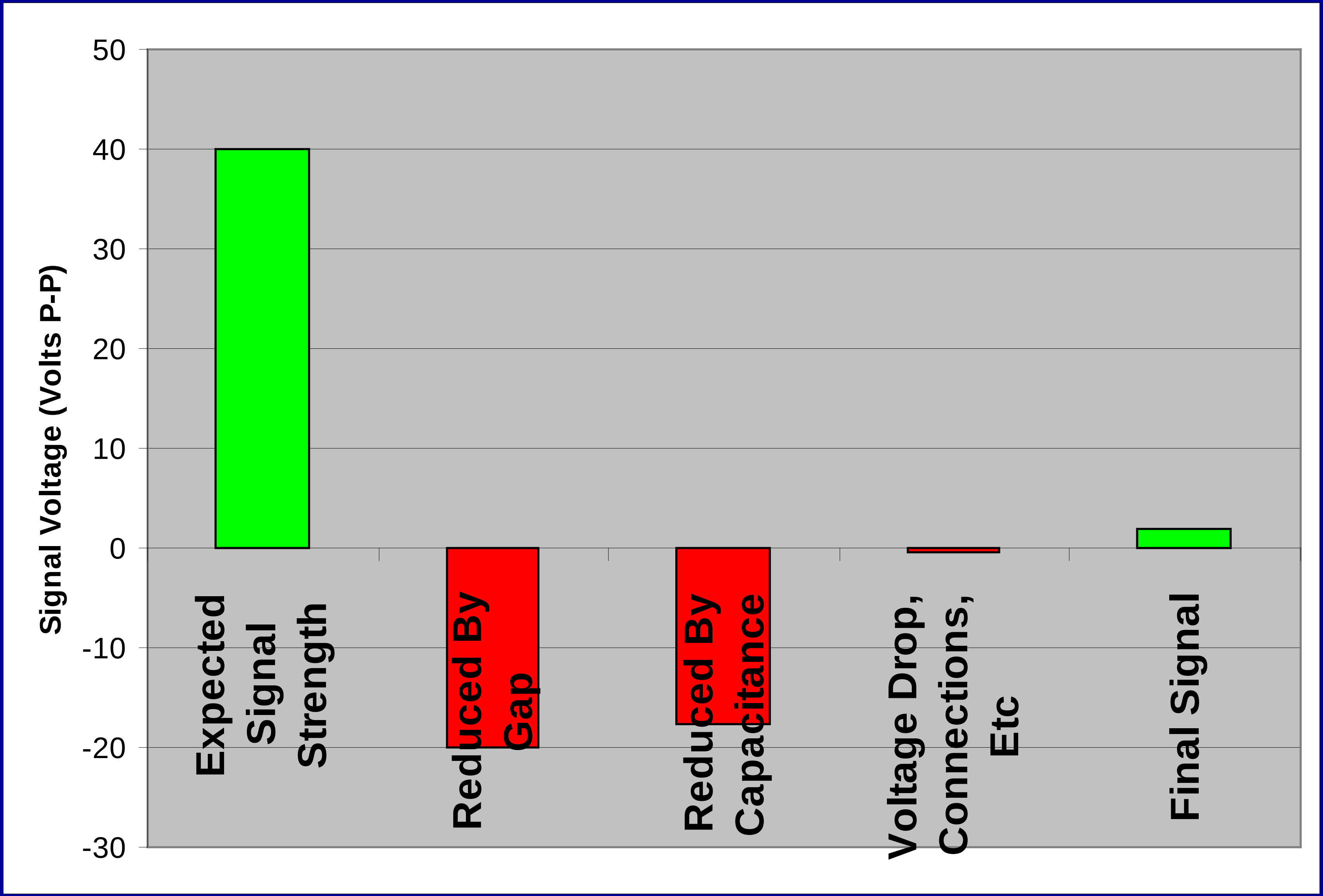
- Signal is less than expected at the deck, but it is even lower at the control room.

- Speed probe voltage *transmitted* is a function of:
  - Capacitance of the wire (unit capacitance x length)
  - Frequency of the signal
  - Probe resistance and inductance
  - Quality of connections, voltage drop due to wire resistance, shielding and grounding.

Signal Voltage Reduction



Signal Strength Reduction Summary



Lessons Learned

- Did the overspeed trip system perform its function?
  - Yes!
- Could it have suffered the same failure mechanism as the governor?
  - Yes!
- This was not a governor failure – it was a speed signal failure that affected the governor but could have affected the overspeed trip system, or both.

Lessons Learned (cont’d)

- New system that is pending installation has:
  - Low capacitance wire and a lower tooth count speed gear
  - A probe whose characteristics generate a higher voltage and help maintain that voltage when transmitted
  - Modified bracket that maintains a stable gap, and
  - Governor logic that is high signal select regardless of the “good” probe count.

Lessons Learned (cont'd)

- Speed signal loss calculations need to be an integral part of electronic governor and overspeed trip system design.
- Bracket design should be thoroughly evaluated.
- Probe voltage *generated* and *transmitted* should be compared to calculated values during actual system tests.

Lessons Learned (cont'd)

- Consideration should be given to system testing up to maximum governor speeds. Full overspeed trip tests should be considered for new designs that project marginal signal strength.
- Review governor logic to ensure it suits process requirements.
- Operator response to governor alarms needs to be clearly defined.

Disclaimer

Backup Slides

Calculation of Approximate Signal Loss

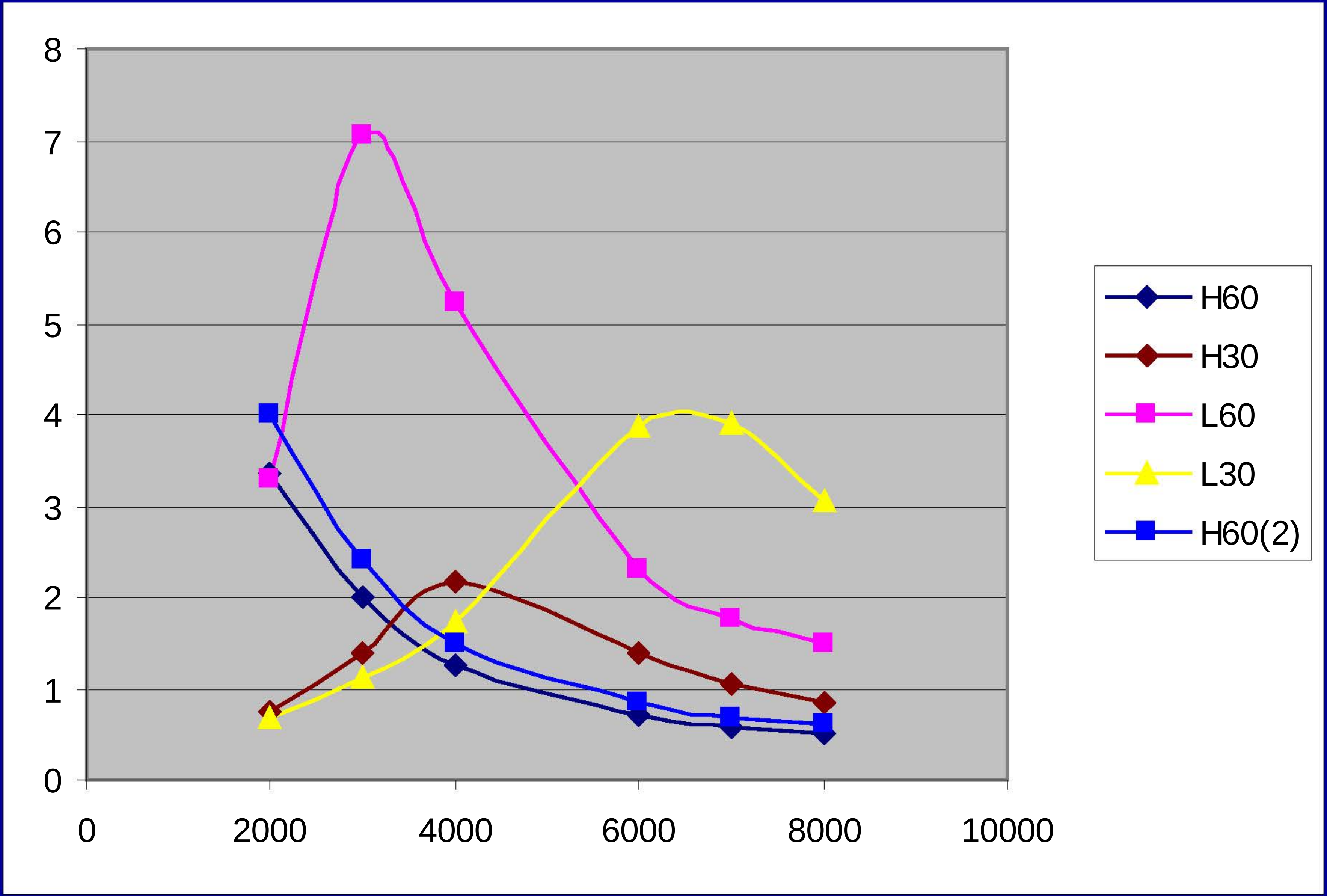
- Given:
  - 1200 ft of 64 pF/ft wire
  - 60 tooth speed gear, 7 inches in diameter turning at 8100 rpm
  - Probe inductance 125 mH with DC resistance of 700 ohms
- Calculations:
  - Cable mutual capacitance is 76,800 pF
  - System frequency is 8100 Hz – 123 µsec period
  - Inductive reactance – 2 x pi x Freq x probe inductance = 6361 ohms
  - Total impedence = $(6361^2+700^2)^{1/2}$ = 6400 ohms
  - Time constant, Rc = 6400 x 76,800 = 491 msec
  - Half cycle, t = 61.5
  - Signal percent amplitude = 100 (1-e^(-t/Rc)) = 12%
- Result:
  - 20 V P-P x 12% = 2.4 V P-P signal

Probe Test Results

- These calculations, conditions similar to the existing installation, and lower capacitance wire were tested at a local repair facility to validate the explanation.

- While not an exact representation, the trends closely matched what was observed in the field.

Shop Test Data



Signal Before and After Patch

500