Real-time resonant magnetic perturbations feedback control system for tearing mode suppression on J-TEXT

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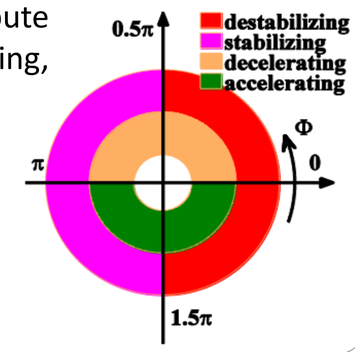
Abstract

- 2/1 Resonant magnetic perturbations(RMP) and 2/1 tearing modes(TMs) can interact
- Apply RMP in different phase of TM island will produce different effect.
- When the O point of TM island passes through the Mirnov probe, the Mirnov signal will zero-cross.
- Output the control signal by real-time comparing the phase of TM island and the given phase in real-time.
- Due to the Mirnov signals are noisy, error correction methods arenecessary.
- The control period of real-time feedback control system is within 500ns to ensure the precision within 2 degrees.

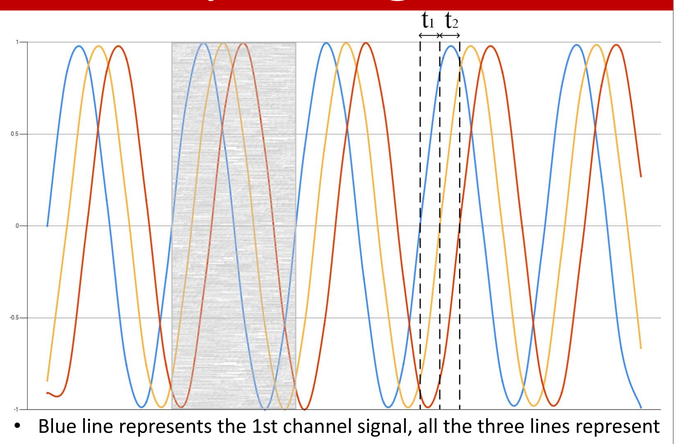
Principle

- Applied in different phases, RMP can contribute stabilizing, destabilizing, accelerating, decelerating effect.
- The interactions depend on the phase shift Δα.
- The stabilizing region is from 0.5π to 1.5π while the accelerating region is from π to 2π. Ideally, apply RMP in this rage can produce good results.



Real-time phase compare algorithm

- In an α-cycles, each β-period costs the same phase.
- Current β-periods can be predicted by the last β-periods
  - There are N channels in each α-cycle.
  - N^{th} β-period begin is t_n(N^{th} channel zero-crossing)

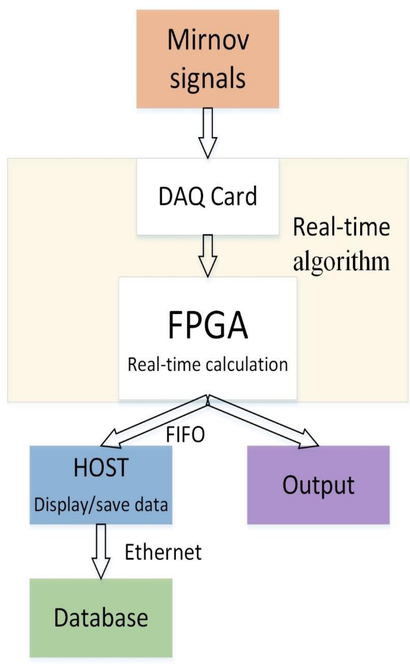


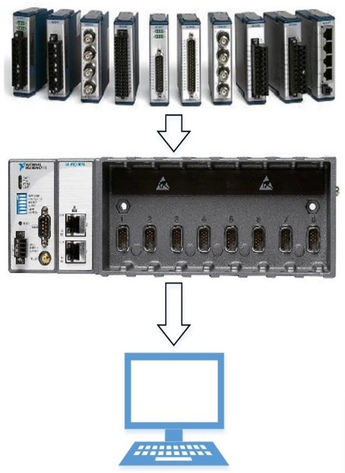
- Blue line represents the 1st channel signal, all the three lines represent three adjacent channels.
- The gray box indicates a complete α-cycle.
- The t_1 and t_2 are the adjacent β-periods.

$$\Phi_{t_n} = \frac{360 \times (n-1)}{N}$$

$$\Phi_t = \frac{t - t_n}{t_n - t_{n-1}} \frac{360}{N} + \frac{360 \times (n-1)}{N}$$ (Φ_t is the island phase at t.)

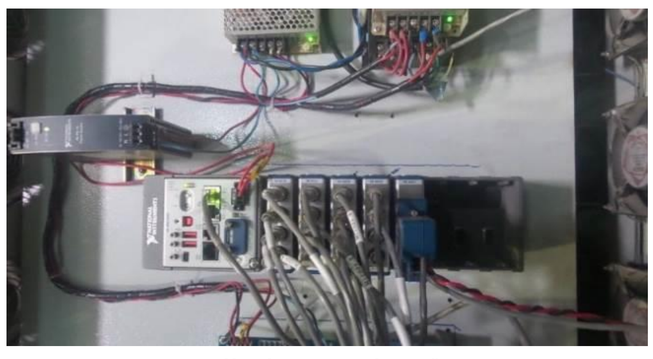
Implementation based on NI cRIO





Overall design of control system

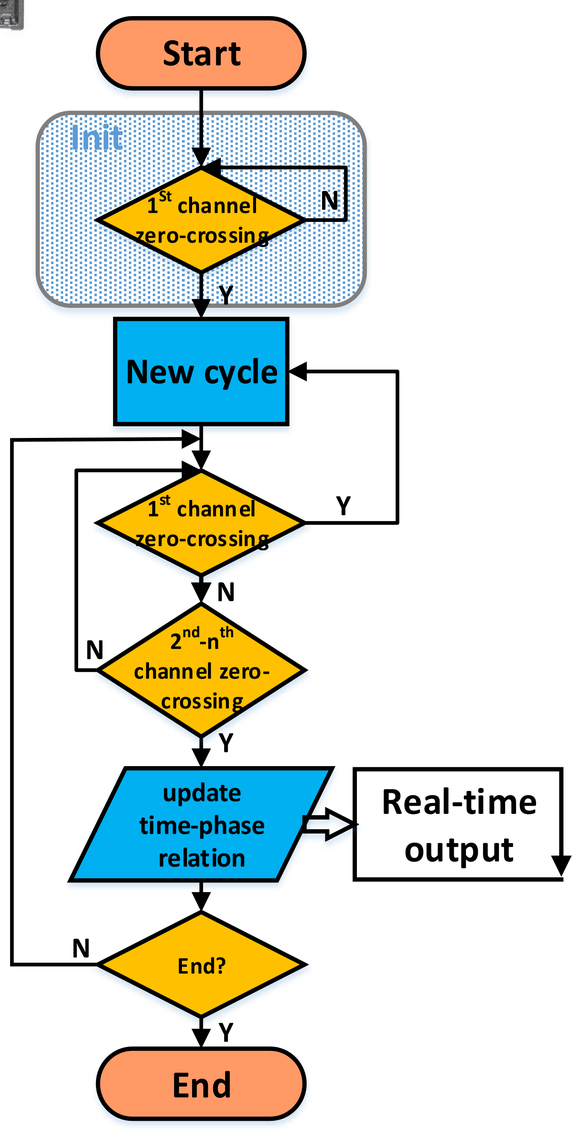
- Integrate data acquisition
- FPGA for real-time calculation
- Archive raw data to HOST by FIFO
- Upload data to Database by Ethernet
- Use LabVIEW and LabVIEW FPGA



Installed cRIO plantform

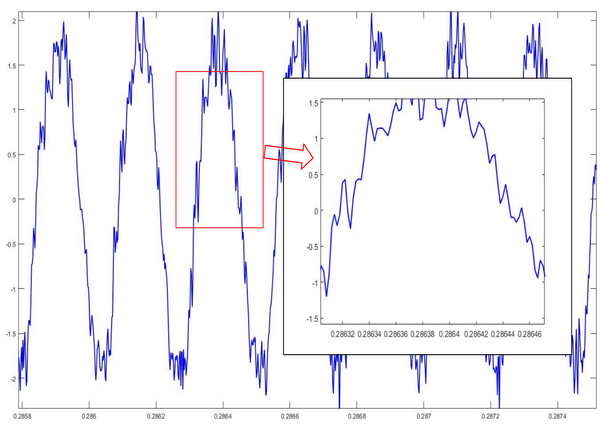
- cRIO 9039, algorithm on the FPGA
- 1 NI 9401 for DIO
- 4 NI 9223 for requiring data

- 1^{st} signal zero-crossing
  ---- new cycle
- 2^{nd} –n^{th} signals zero-crossing
  ---- update time-phase relation
- Obtain real-time phase using latest time-phase relation

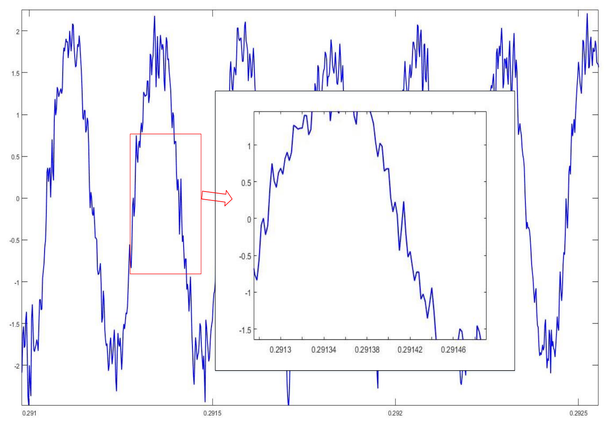


Work flow of real-time phase calculation algorithm on FPGA

Real-time error correction



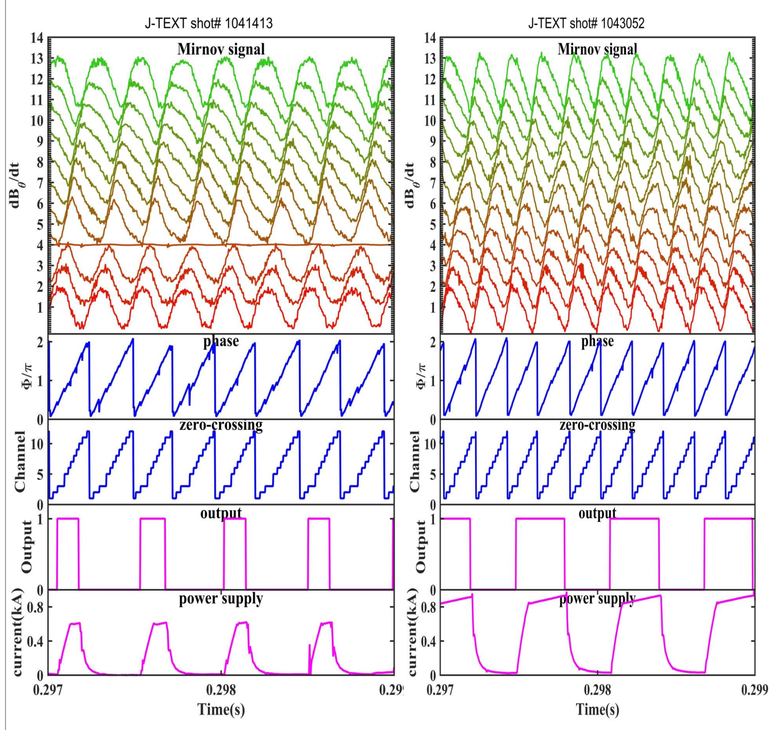
- multiple zero-crossing around zero amplitude in Mirnov signal



- Wrong zero-cross during the half cycle due to interference

- Zero-crossing direction: only minus-plus
- Only recognizes the first zero-crossing point and ignore the rest within a certain time span
- Integrates one-fourth cycle, only when the integral value is less than zero, the minus-plus zero-crossing is considered to be effective.
- Does not affect the calculation speed.

Experiment result



(a) (b)

- ✓ Protect pulsed power supply (response frequency is insufficient)
- ✓ Reduce eddy current
- ✓ Reduce the output frequency significantly
- Output frequency: (a)1/2 frequency (b) 1/3 frequency
- Duty cycle: (a)25%, (b)50%
- Output current: (a)0.4kA (b)1kA