The Premier Advanced Recording Technology Forum

Sensorless Motor Control for Tape Drives

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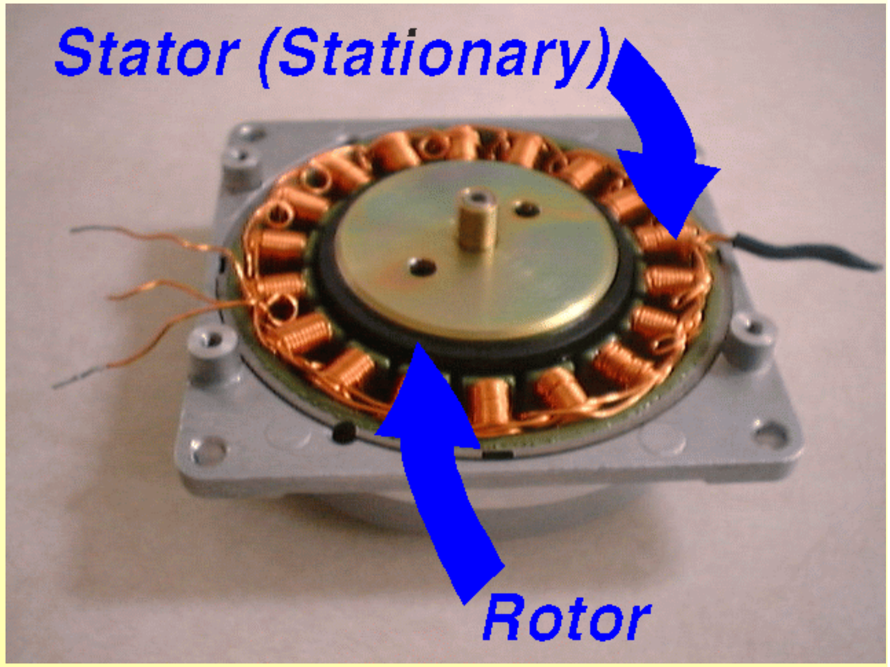
Sensorless Motor Control For Tape Drives

- New generations of tape drives are reducing size and cost, while increasing requirements for performance and reliability
- Size, cost, and performance of reel-motor control components has become an issue
- In response, ME II has been working on new techniques to eliminate mechanical and optical parts from the motor control subsystem

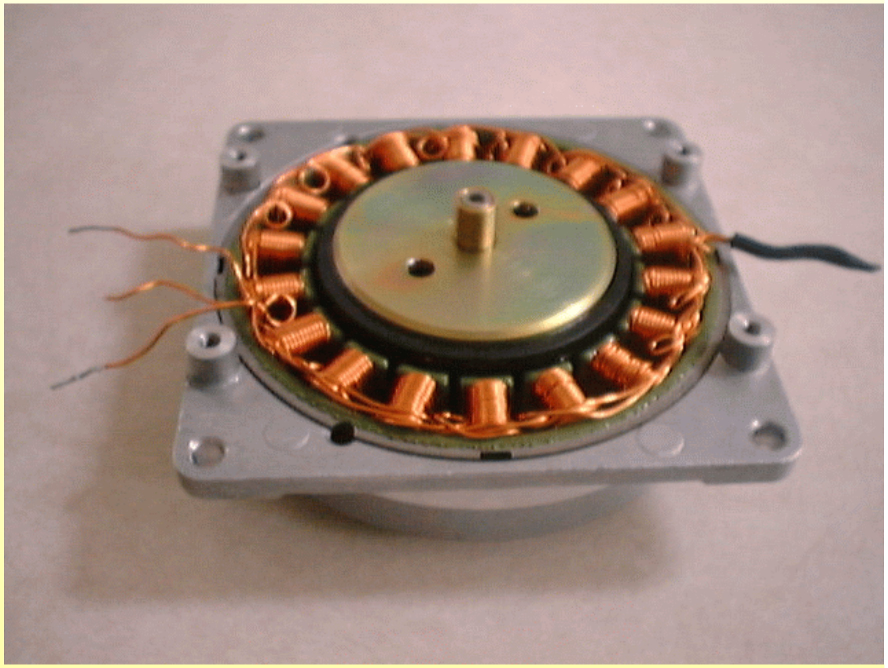
Brushless DC Motors

- Modern tape drives typically spin the reels with brushless DC motors
- Many advantages
  - As mechanically simple as AC motors
  - Variable RPM like DC brush motors
  - Low maintenance, long life



Brushless DC Motors

- Require sophisticated drive electronics for motor commutation
- Electronic commutation is based on some form of rotational position sensing
- Rotation sensor technologies used today have drawbacks



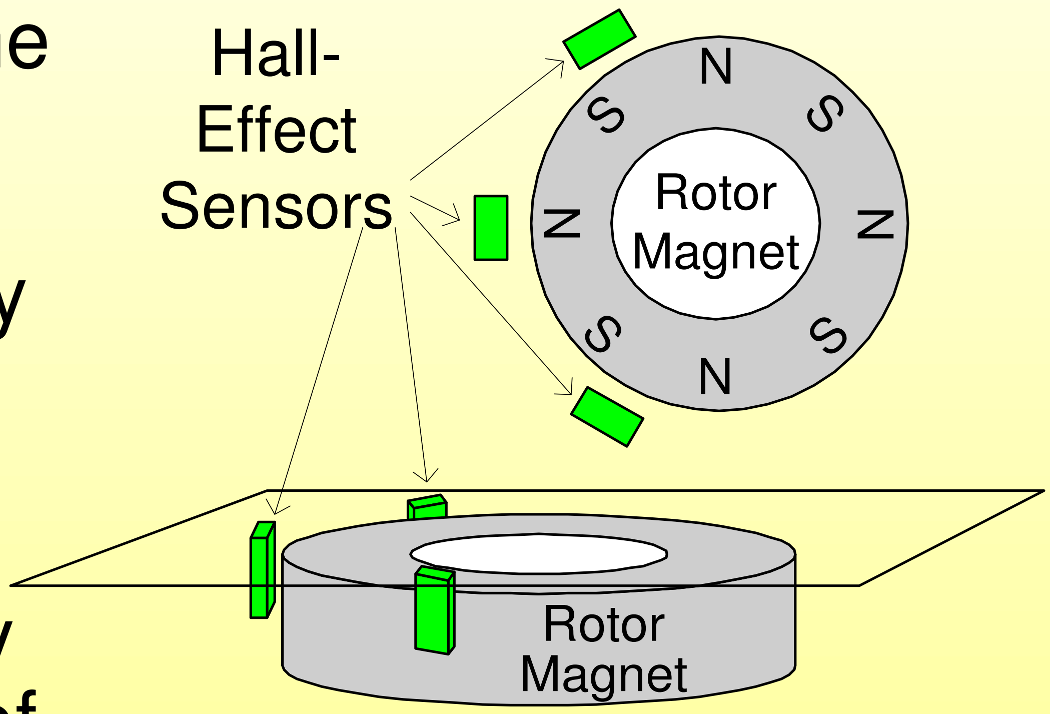
Rotation-Sensor Technologies

- Hall-effect magnetic sensors
- Optical encoders
- Many tape drives on the market contain both Hall-effect ***and*** optical rotation sensors

Rotation Sensor Technologies

Hall-Effect Rotation Sensors

- Sensors detect the magnetic poles of the motor rotor
- Resolution limited by number of sensors.
- Accuracy limited by positioning accuracy and gain tolerance of the sensors.



Rotation-Sensor Technologies

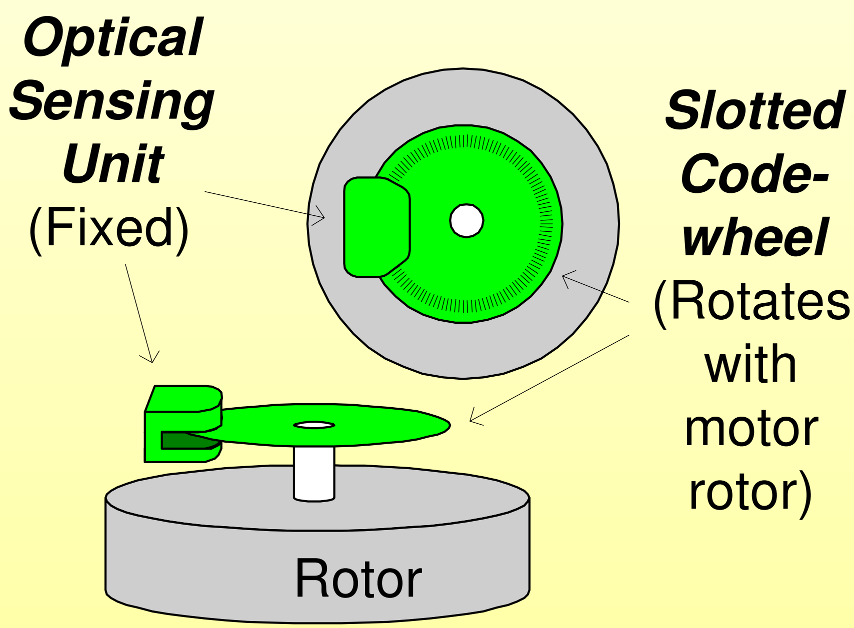
Hall-Effect Rotation Sensors

- Advantages
  - Low cost
  - Simple, reliable
  - Absolute position sensing for commutation
- Disadvantages
  - Low resolution
  - Low accuracy may cause torque ripple
  - System often requires additional high-resolution rotation sensor

Rotation Sensor Technologies

Optical Encoders

- Optical unit shines light beams through the slots in the codewheel, detecting interruptions as the slots pass
- Slots moving through the sensor are counted electronically, this gives the accumulated angle of rotation



Rotation Sensor Technologies

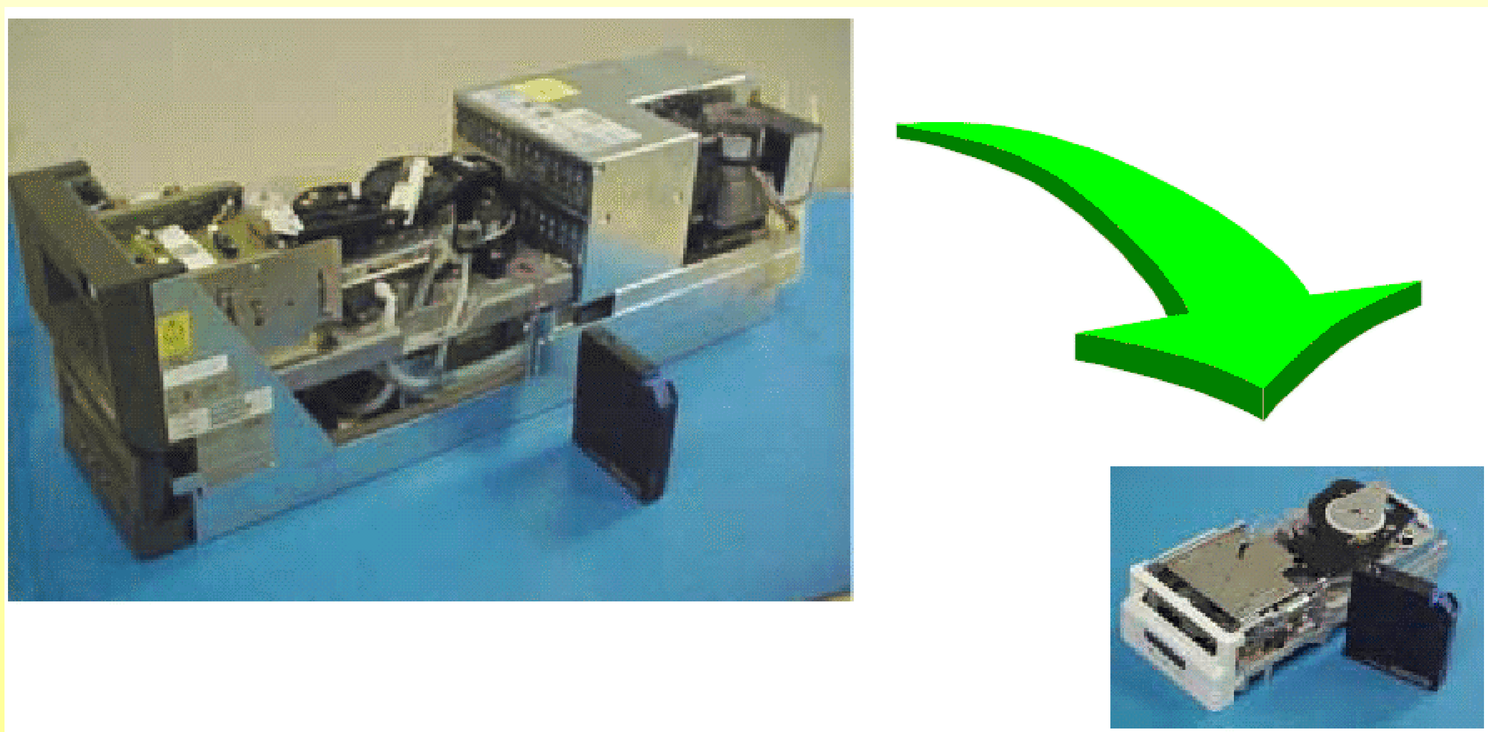
Optical Encoders

- Advantages
  - High resolution, precision
- Disadvantages
  - High cost
  - Incremental position sensing (requires initialization)
  - Electronics needed for decoding/accumulation
  - Sensitivity to contamination and ambient light
  - May require alignment/adjustment

Rotation Sensors

Problems for use in tape drives

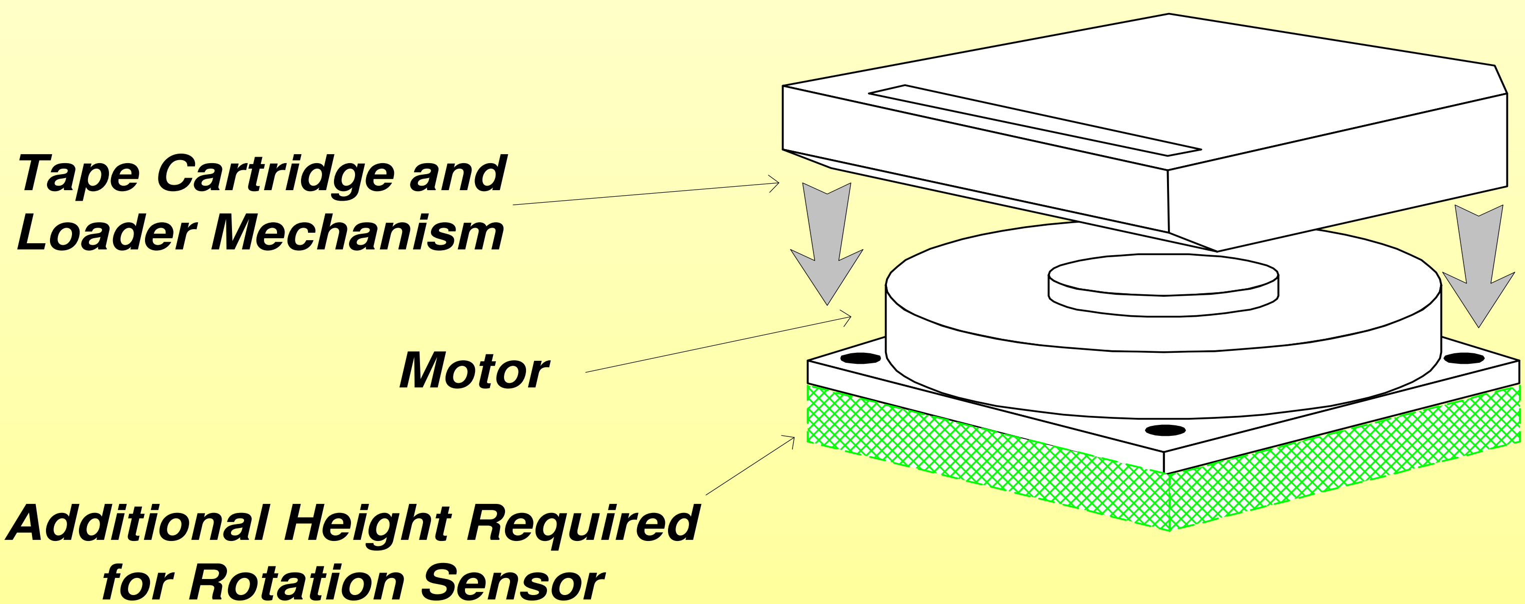
- Many newer tape drives are 5¼ inch form factor or smaller, sometimes even half-height



Rotation Sensors

Problems for use in tape drives

- Occupies height in a critical area



Rotation Sensors

Problems for use in tape drives

- Sensor misalignment or inaccuracy causes torque ripple as motors turn — this results in tension and speed variations in the tape
- May add manufacturing steps
- May add maintenance issues
- May add extra parts cost

Sensorless Motor Control

Advantages

- Removes height allocation for rotation-sensor hardware
- Moves sensing function into electronics, eliminating moving parts, mechanical adjustments, maintenance
- Position information comes directly from electromagnetic characteristics of motor, so sensing is always in alignment

Sensorless Motor Control

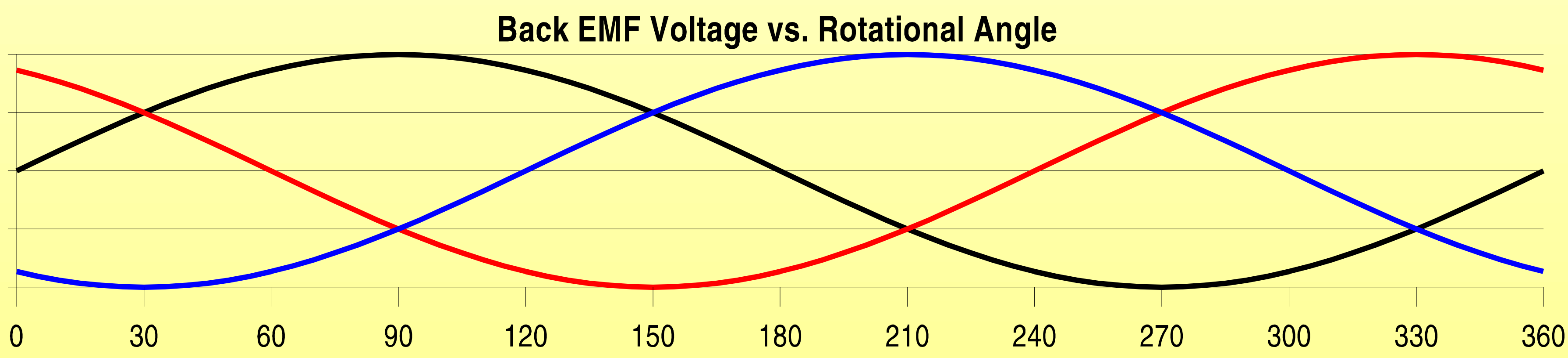
Existing Approaches

- Back-EMF sensing
- Added sense windings on motor
- Measure motor winding impedance changes
  - “Probing” with current pulses
  - High-frequency sense carrier

Sensorless Motor Control

Back-EMF sensing

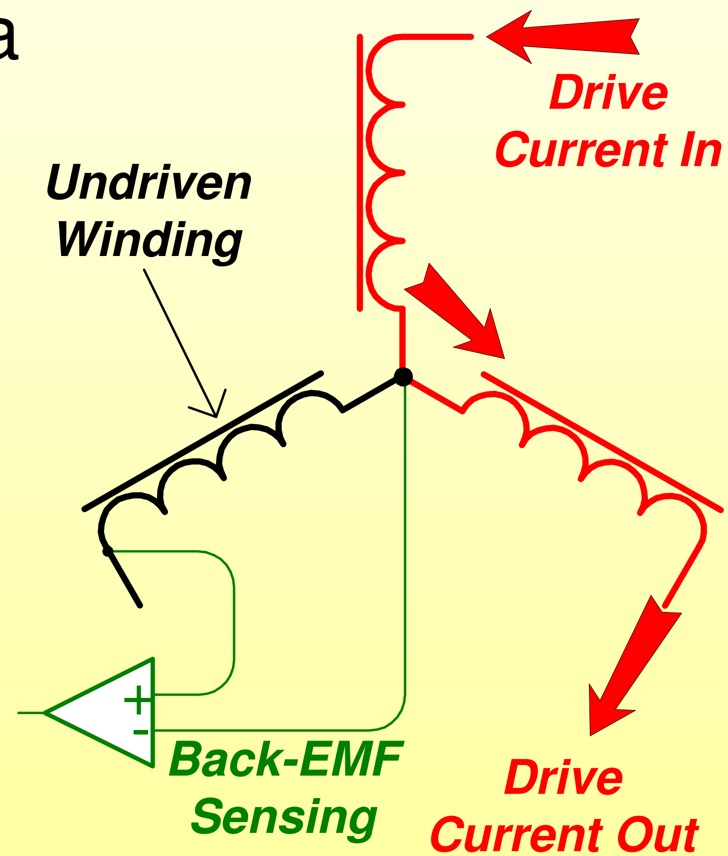
- Senses induced voltage from rotor rotation
- Simple, proven
- Signal amplitude is proportional to motor speed, so this does not work when motor is stopped or rotating slowly
- Very commonly used in disk drives and fans



Sensorless Motor Control

Back-EMF sensing

- Typical brushless motor uses a three-phase Y stator configuration
- Typical drive puts current through only two of the three legs at any time
- Back-EMF sensing measures voltage across the undriven winding
- Drive and sensing must switch legs as the rotor turns



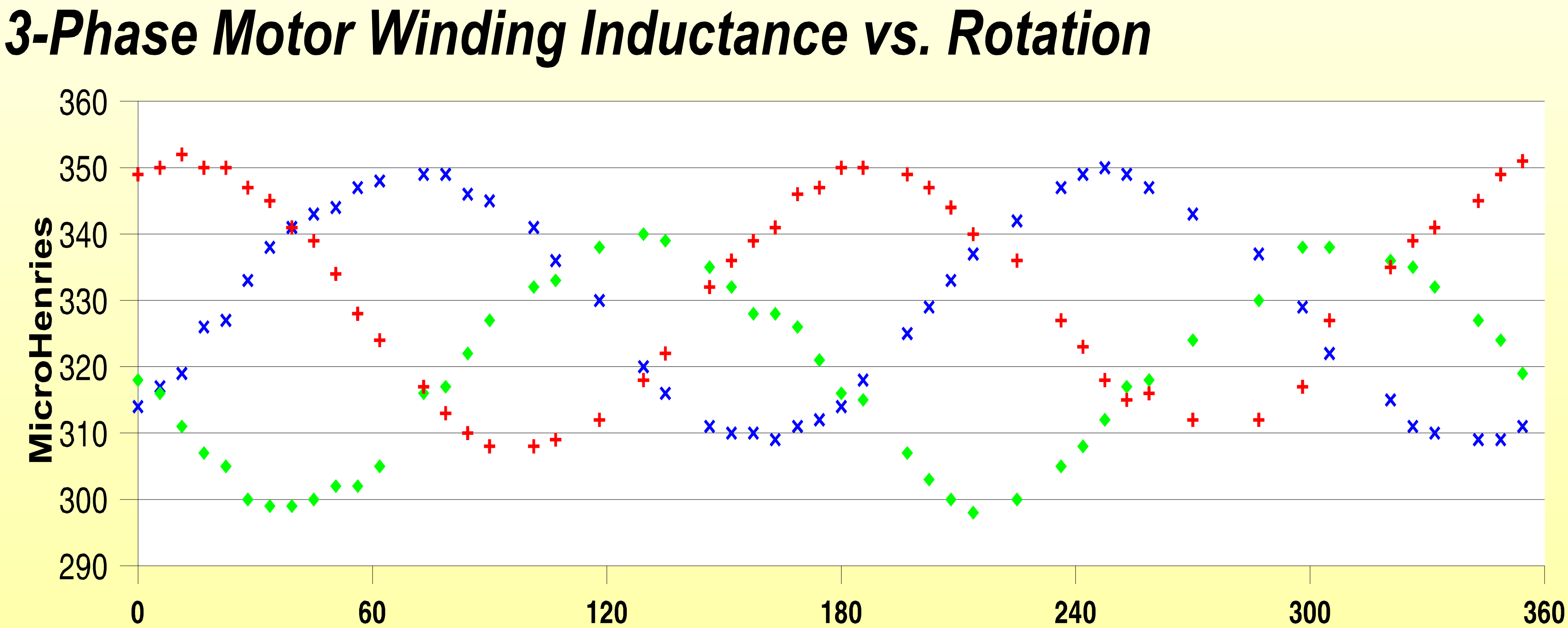
Sensorless Motor Control

Added sense windings

- Extra complexity added to motor
- Custom motor with extra manufacturing steps
- Several approaches, none in common use

Sensorless Motor Control

Winding impedance varies with rotation



- Note that pattern repeats every 180 degrees

Sensorless Motor Control

Measuring dynamic motor impedance

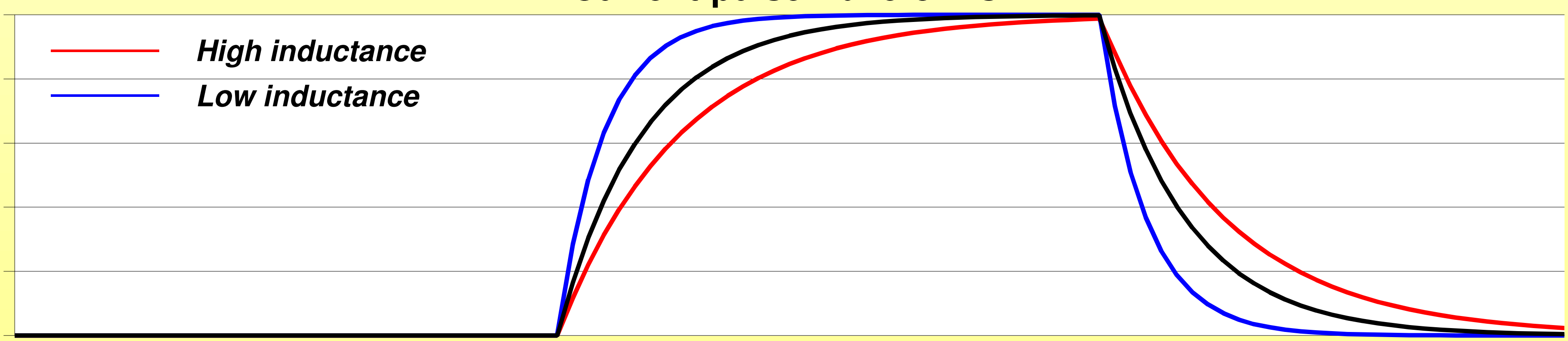
- High-frequency sense carrier
  - Works by superimposing a high frequency signal onto the drive current
  - Some academic research in this area
  - No known commercial usage

Sensorless Motor Control

Measuring dynamic motor impedance

- "Probing" with current pulses
  - Pulse rise/fall time varies with winding inductance
  - At high current levels, this technique can detect polarity of the magnetic rotor pole, so it can distinguish between the two 180-degree half cycles

Current-pulse waveforms



Sensorless Motor Control

Measuring dynamic motor impedance

- “Probing” with current pulses
  - Works well when motor stopped and turned off
  - Can often be implemented in firmware with no extra electronics
  - Disturbs motor torque if used while motor is working

Sensorless Motor Control

Problems for use with Tape Drives

- Back-EMF sensing works only when motor is rotating
  - Tape drives must provide good torque/tension control at all speeds including stopped
- Sense windings and high-frequency sense carriers have not been made practical
- Current-pulse probing disturbs motor torque and causes tension disturbances

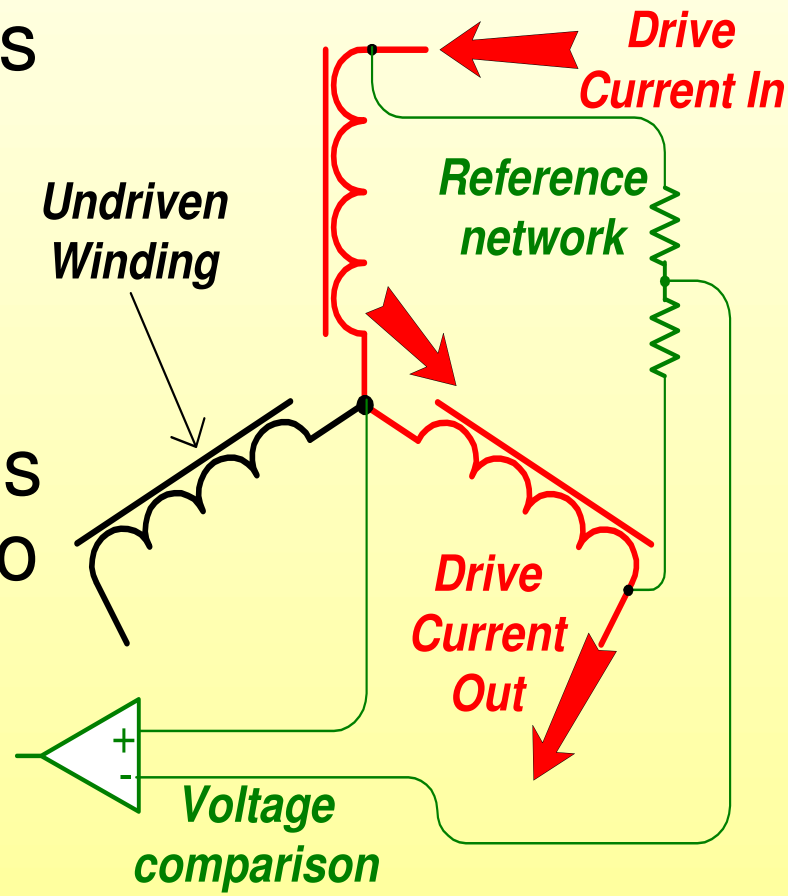
A New Approach to Sensorless Motor Control

- Combines several sensing techniques
- Works under all motor conditions
- High resolution position and speed measurements
- No additional windings or high-frequency signals required

A New Approach to Sensorless Motor Control

Motor-winding impedance ratio measurement

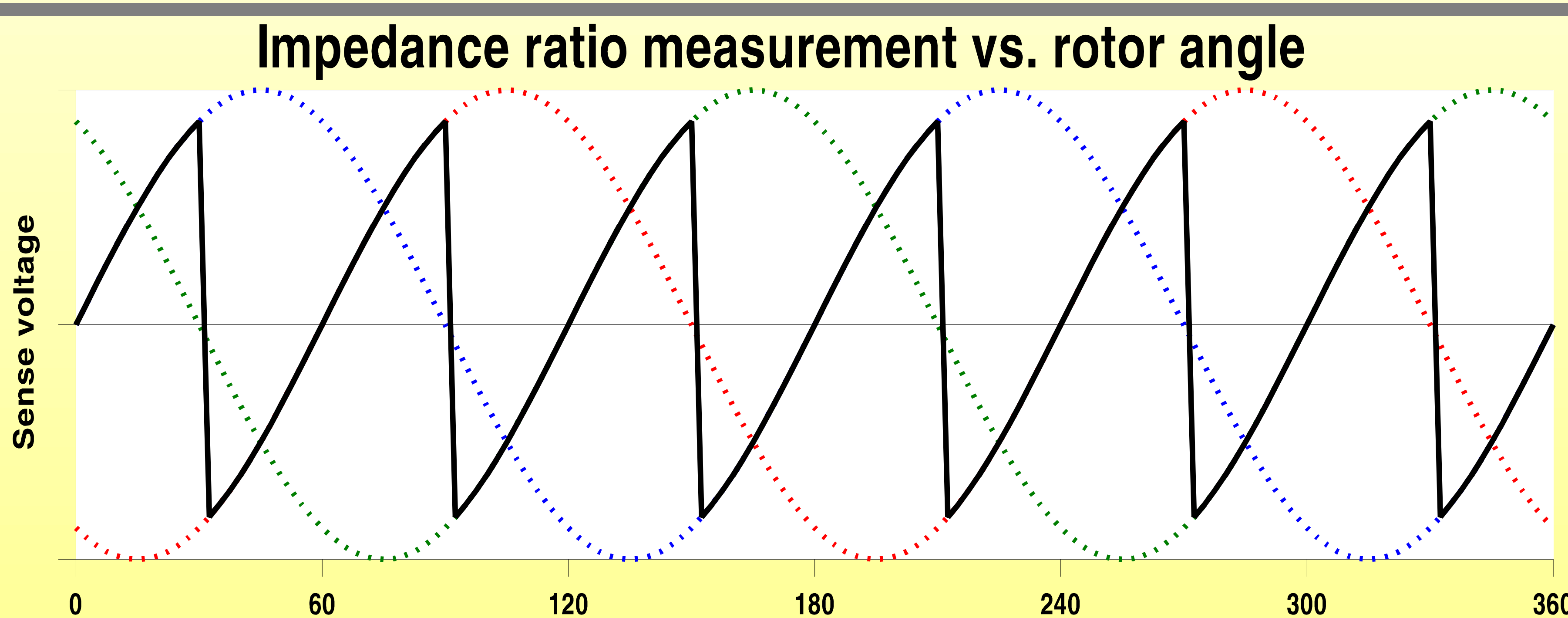
- Reference network simulates voltage of an ideal winding with no impedance variation
- Windings form a voltage divider; impedance variations cause center-node voltage to vary
- Comparison of voltages yields sense signal



A New Approach to Sensorless Motor Control

Motor-winding impedance ratio measurement

- Sense voltage for each phase is roughly sinusoidal. Commutating between phases yields the black line shown below



A New Approach to Sensorless Motor Control

Motor-winding impedance ratio measurement

- Sense voltage depends on ratio of impedance of two windings
- Ratiometric measurement compensates for many disturbances:
  - Drive current
  - Drive voltage
  - Temperature

A New Approach to Sensorless Motor Control

Motor-winding impedance ratio measurement

- Problem: Impedance pattern repeats every 180 electrical degrees
  - Can't distinguish between halves of the full 360 degree cycle
- Solution: Position must be initialized by another sensing method
  - Once initialized, position is tracked incrementally
  - Current-pulse "probing" works well for initialization

A New Approach to Sensorless Motor Control

Motor-winding impedance ratio measurement

- Interaction with back-EMF
  - As motor RPM increases, back-EMF influences the center node voltage
  - Back-EMF is predictable and can be compensated
  - At medium to high RPM, it may be easiest to simply use back-EMF position-sensing

A New Approach to Sensorless Motor Control

Motor-winding impedance ratio measurement

- Requires some current through windings at all times to track position
  - Not a problem when tape is under tension
  - When motor is unloaded, a “trickle” current must be passed through the windings

A New Approach to Sensorless Motor Control

Summary

- Use multiple sensing techniques under different motor conditions
  - Initialization after power-up, with motor in completely unknown rotational position
  - Position tracking at low RPM
  - Position tracking at high RPM

A New Approach to Sensorless Motor Control

Summary

- Initialization after power-up
  - Initialization using current-pulsing can often be done in firmware with no added circuitry
  - Will be done without tape under tension, so torque disturbances are not important
  - Initialization could also use a single low-resolution Hall or optical sensor

A New Approach to Sensorless Motor Control

Summary

- Position tracking at low RPM
  - Use winding impedance ratio method, comparing motor center-node voltage with a reference network voltage
  - Motor current must never be completely turned off, a trickle-current must be run through the windings to maintain tracking

A New Approach to Sensorless Motor Control

Summary

- Position tracking at higher RPM
  - Back-EMF voltages will interact with the impedance ratio sense voltage
  - Back-EMF sensing can be used at these higher rotational speeds
  - Another possibility is to use impedance ratio for position tracking, with compensation for back-EMF effects

A New Approach to Sensorless Motor Control

Summary

- No changes to motor
- No changes to motor-driver
- No mechanical adjustments or alignment needed
- All added complexity is in control electronics

Conclusions

- It will be possible to use sensorless motor control in future tape drives
  - Reduced size requirements
  - Better performance than Hall-effect sensors
  - Lower cost than optical encoders
- This technology is also useful in other application areas
  - Robotics
  - Laser printers

Conclusions

- Mountain Engineering II has built prototype motor controllers to prove feasibility of these techniques
- Development continues, to refine them for volume production
- This technology will help meet the challenges of new generations of tape drives, for smaller size and better price/performance