Automotive Testing Expo 2006
(Ed Lee, Powertec Industrial Motors)

Torsional Vibration Testing Using High Response Servo Motors and Drives

Simulating Engine Torque Pulses to Test Engine Components

The Facts

- Actual on-engine testing
  - Expensive
  - Time consuming
  - Impractical for production testing
- Testing Required by most customers
  - At design-proof level
  - Reliability
  - Production testing 100% with records
  - Helpful if computer based

The Need

- Velocity Mean at up to 6000 rpm or more
  - Duplicating Crankshaft effects requires +- 5% or more velocity variation
  - Rate of torque variation up to 100 cycles per second
- Must be readily adjustable for velocity, variation, and cycle rate.

The Need (cont'd)

- Engine Parts and accessory reliability
- Torsional Stress caused by Engine
  - Primary and Harmonic
- Examples
  - Superchargers
  - Alternators
  - Counter-balancers
  - Shafts and transmissions

The Need (cont'd)

- How to Test a wide array of items at different speeds/frequencies
- Mechanical eccentric machines too inflexible
- Hydraulic machines too limited and too much maintenance
- DC and AC Electric Motors/Drives Ideal, but limited in performance

The Need (cont'd)

- Speed Requirements 500 to 6000 rpm or more
- Velocity variation 1% to 10% (plus minus around base rpm)
- Cyclic rate up to 100 cycles per second
- Ability to adjust all these parameters in real time

Addressing the Issues

- Dealing with the inertia:
- $T=(I \times \Delta RPM)/(308 \times t)$

(Where T= torque in lb-ft, I= inertia in lb-ft^2, and t= time in seconds)

- This means changing velocity from one rpm to another in a certain time requires TORQUE to produce the change

Addressing the Issues (cont'd)

- An Example:
  - Inertia 1 lb-ft^2
  - Speed 2000 rpm
  - Variation in speed +-5%, therefore 200 rpm
  - Cyclic Rate 100 per second (100 Hz) or time per cycle is .01 sec

Addressing the Issues (cont'd)

- Solution:
  - Torque Required = 65 lb-ft rms
- So we now know we need a motor to produce 65 lb-ft of torque continuously to run the test continuously.
- Since we have to run the unit actually coupled to a motor let us assume the motor inertia equals the load inertia, or an additional 1 $lb\text{-}ft^2$

Addressing the Issues (cont'd)

- The required torque obviously is doubled, making it clear that the load inertia and the motor inertia must both be considered. In many cases such as this the motor inertia becomes the limiting factor, not the load inertia

Addressing the Issues (cont'd)

- Now to consider POWER required
  - The speed is 2000 rpm and the torque required continuously is 130 lb-ft.
  - HP = T x N/5250
  - Power required from the motor is therefore is 50 hp
  - Half of the power accelerates the load and half accelerates the motor itself

THE PROBLEM!!!!!!

- How do we find a motor that will produce 50 hp at 2000 rpm and have an inertia of only 1 lb-ft^2
- Look at a 50 hp DC machine and we find it is in a 368AT frame but has an inertia more than 9 lb-ft^2. Clearly this motor will not even accelerate ITSELF at the required rate.

THE PROBLEM!!!!!!

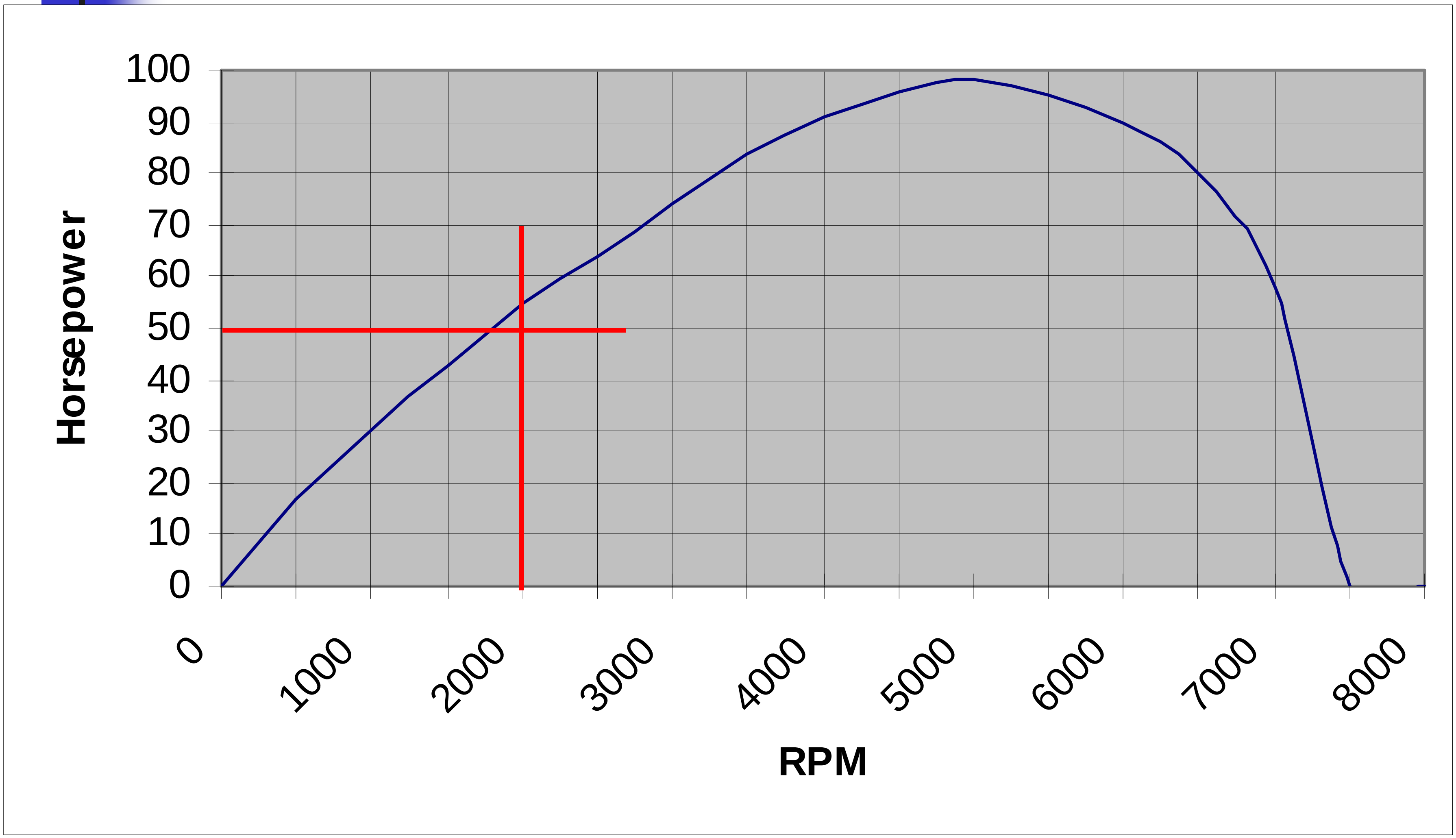
- Can we find an induction motor that will produce 50 hp at 2000 rpm and have an inertia of only 1 lb-ft^2
- Look at a 50 hp AC Induction machine and we find that it is in a 326T frame and also has an inertia of over 9 lb-ft^2 and also therefore will not do the application.

The SOLUTION

- A Brushless motor can be the solution. Using the Powertec catalog speed/torque curves, a 215T frame Rare Earth magnet motor will deliver the torque at 2000 rpm to do this job. Inertia is 0.9 $lb\text{-}ft^2$ therefore meeting the criteria.
- Brushless motors from other manufacturers can be had with similar characteristics

Continuous Power Curve E215T

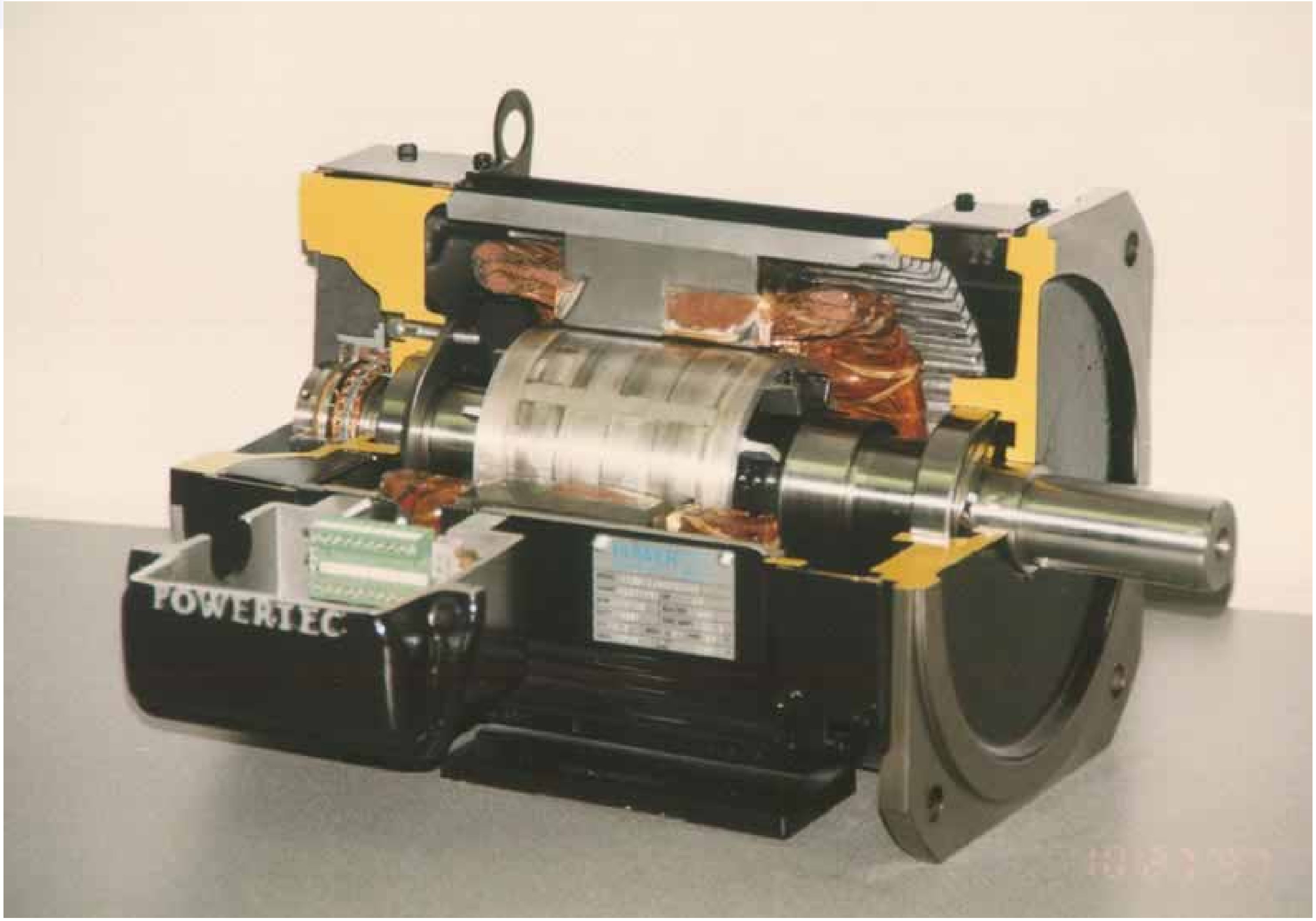
(Powertec Catalog PT-18735, Page 23)



Weight and Inertia Comparison (Ratio = Torque/Inertia Ratio lb-ft/lb-ft^2)

HP	Torque Rated	Frame AC	Wt AC	Inertia AC/Ratio	Frame B'Less	Wt B'Less	Inertia BL/Ratio
10	30	215T	196	1.1/27	E182T	86	0.3/100
15	45	256T	309	1.8/25	ES184T	113	0.4/100
20	60	256T	321	2.3/33	E184T	129	0.5/120
25	75	284T	432	4.0/19	E213T	175	0.8/94
30	90	286T	458	4.7/19	E213T	175	0.8/112
40	120	324T	656	7.8/15	E215T	211	0.9/133
50	150	326T	679	9.7/15	E218T	261	1.1/136
60	180	364T	797	12.2/15	E254T	295	2.4/75
75	225	365T	895	15.3/15	E256T	345	2.9/78
100	300	405T	1232	27.0/11	ES259T	440	3.8/79

Typical Brushless Motor (15hp 182T frame)



The SOLUTION

- The Real issue for a cyclic application is not how much torque a motor will produce but it’s torque to inertia RATIO. In this application solving the equation for T/Inertia = 65
- Therefore any motor doing this application successfully must have a torque to inertia ratio of 65 or greater

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Max Accel rate

- Looking at the formula in yet another way, we can see that one can solve for the acceleration rate the motor itself must have = 65 * 308 or 20,020 rpm/second.
- This is a common way for servo motors to express this torque to inertia performance factor.

Max Accel rate (Cont’d)

- Typical NEMA AC motors and DC machines have max accel rates of 4,000 to 10,000 rpm per second.
- The NEMA AC Induction 50 hp motor from the table is 15 * 308 =4,620 rpm/sec
- Brushless motors range from 25,000 to 40,000 rpm/second
- The E215 frame motor from the table is 41,000 rpm/second

An Actual Example

- A test machine testing crankshaft counter-balancers is required
- Speed of 1200 rpm is required on the part with +-5% variation at adjustable cycle rates up to 100 cps.

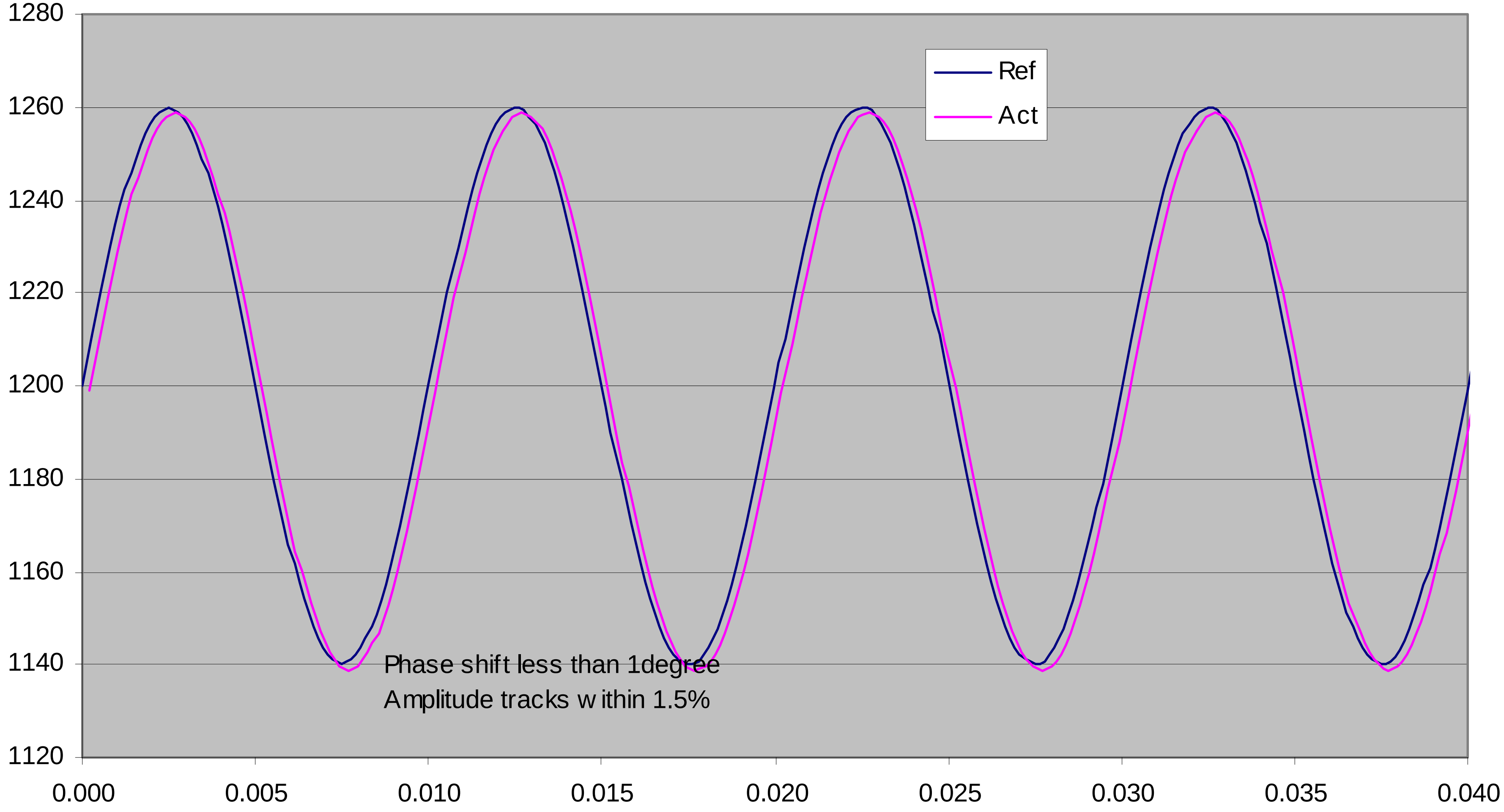
An Actual Example

- An L145T frame motor was available with inertia roughly = to load.
- Motor controller PX-30 provided torque peak up to 200%.
- PLC provided analog reference to produce cycle profile

An Actual Example

- A sinusoidal analog input reference was applied to the drive commanding the required test velocities
- Figure 2 is a reference plot of the command and result.

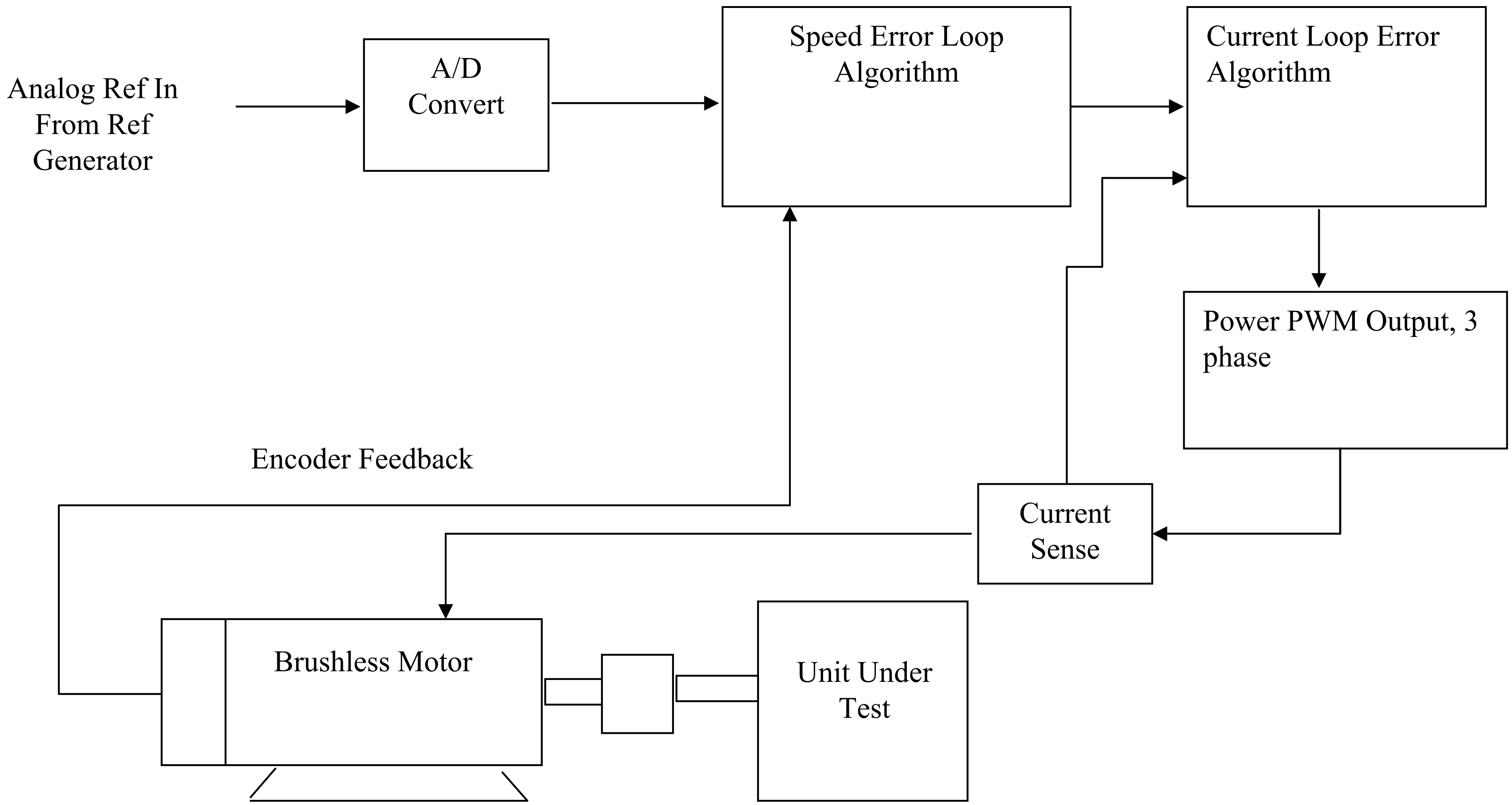
Plot of Actual vs Commanded Velocity Variation



An Actual Example

- The actual velocity tracks the commanded velocity very closely both in phase and in amplitude.
- Both phase and amplitude were varied to verify tracking was accurate over the operating range.

Typical PWM Servo Control



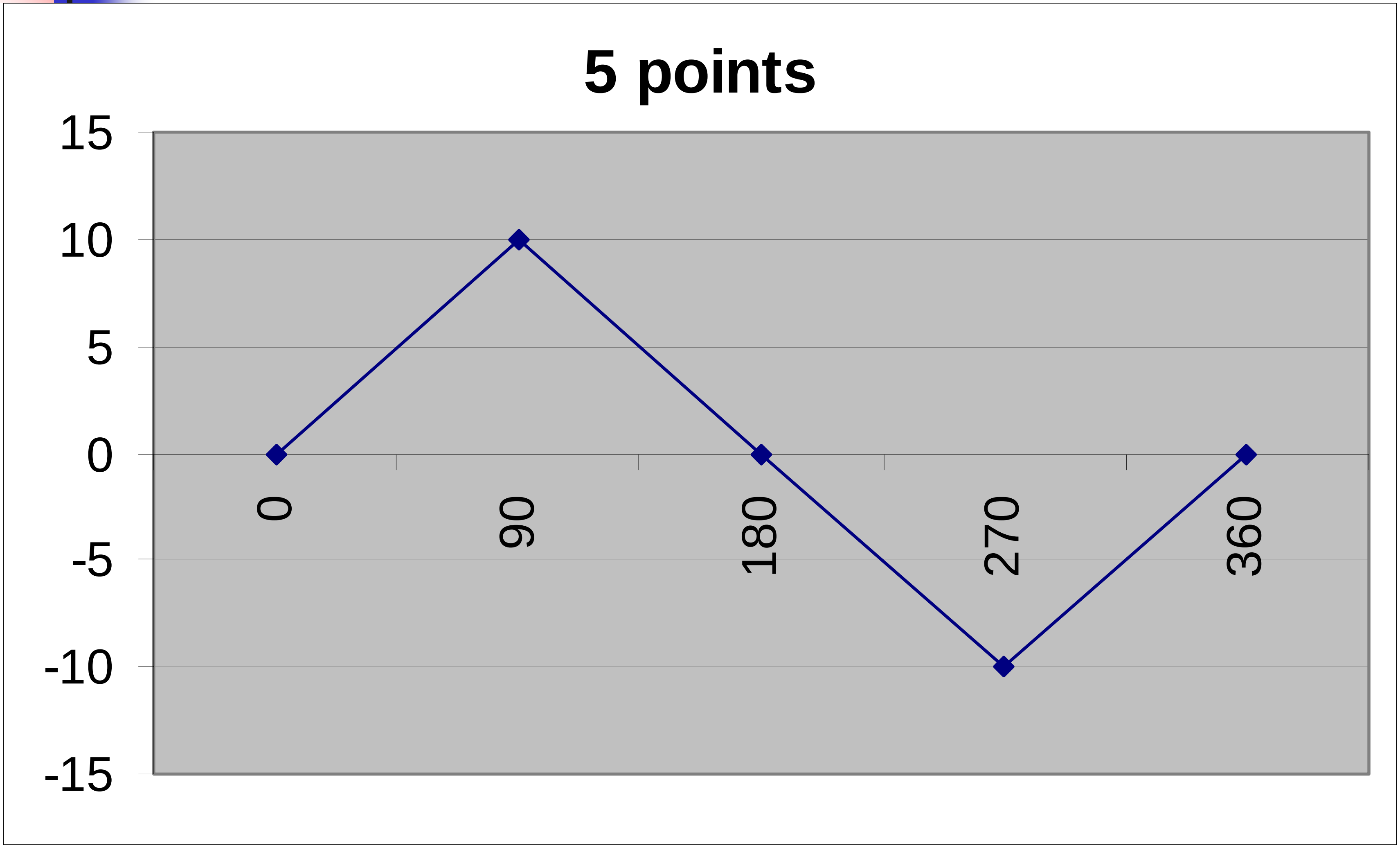
Effects of Controller Bandwidth

- Accepted Nyquist theory suggests control over loop requires 4 to 5 times loop disturbance rate.
- Therefore 100Hz shaft velocity change requires velocity loop of 400 to 500Hz.
- Velocity loop of 500Hz requires current loop of 2kHz to 2.5kHz
- Current loop of 2k to 2.5kHz requires 8 to 12 kHz PWM frequency.

Accuracy and Sample Time

- If disturbance is to be characterized by input analog reference
- A sinewave should have ideally 10 points to define it. More is better. 100hz requires 1000 points per second, 1 ms minimum conversion. Many drives have 2 ms or more update time.
- Accuracy would require 12 bits (4096 Plus/minus). +-6000 rpm would still only give 3 rpm resolution.

Analog input Points



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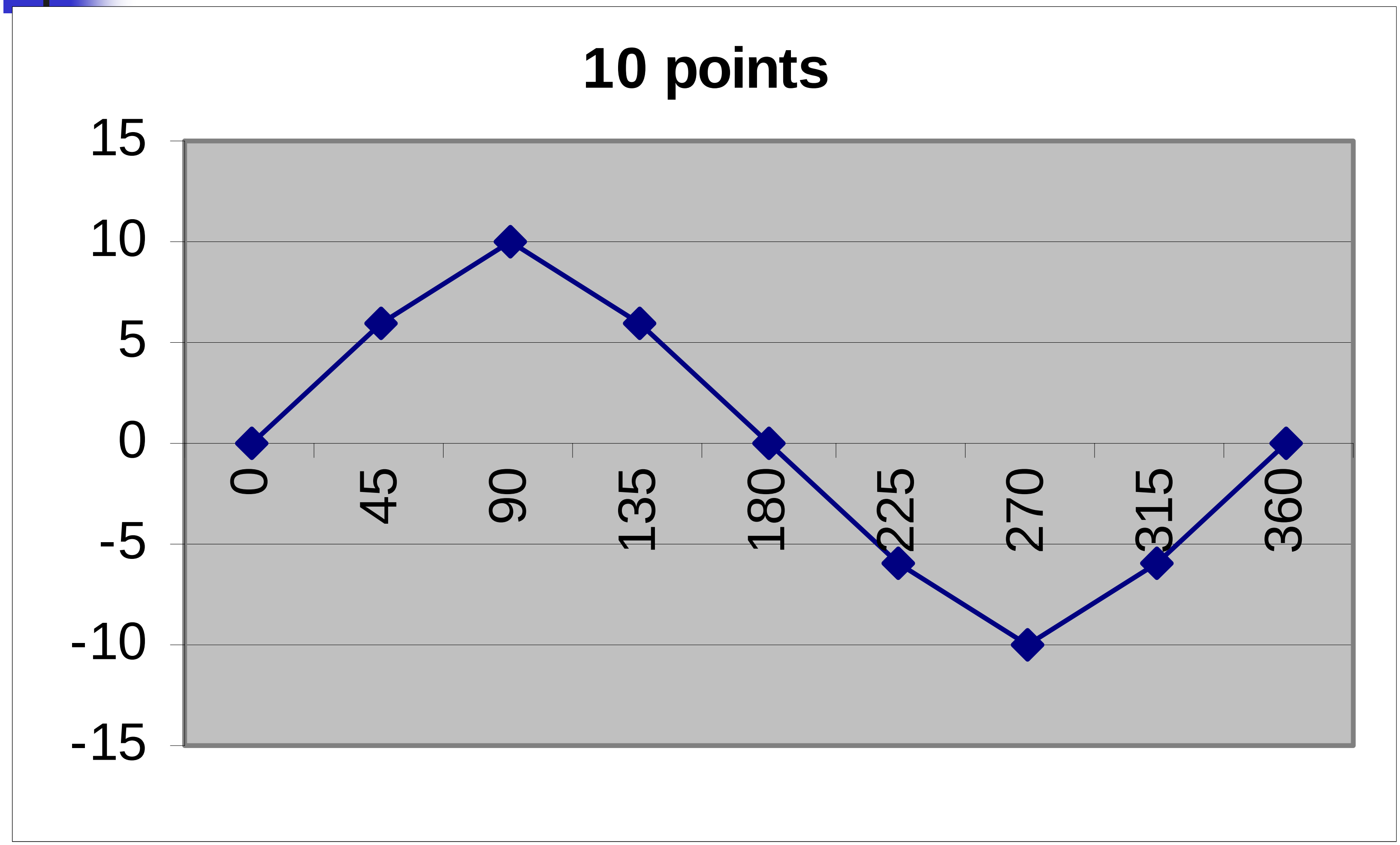

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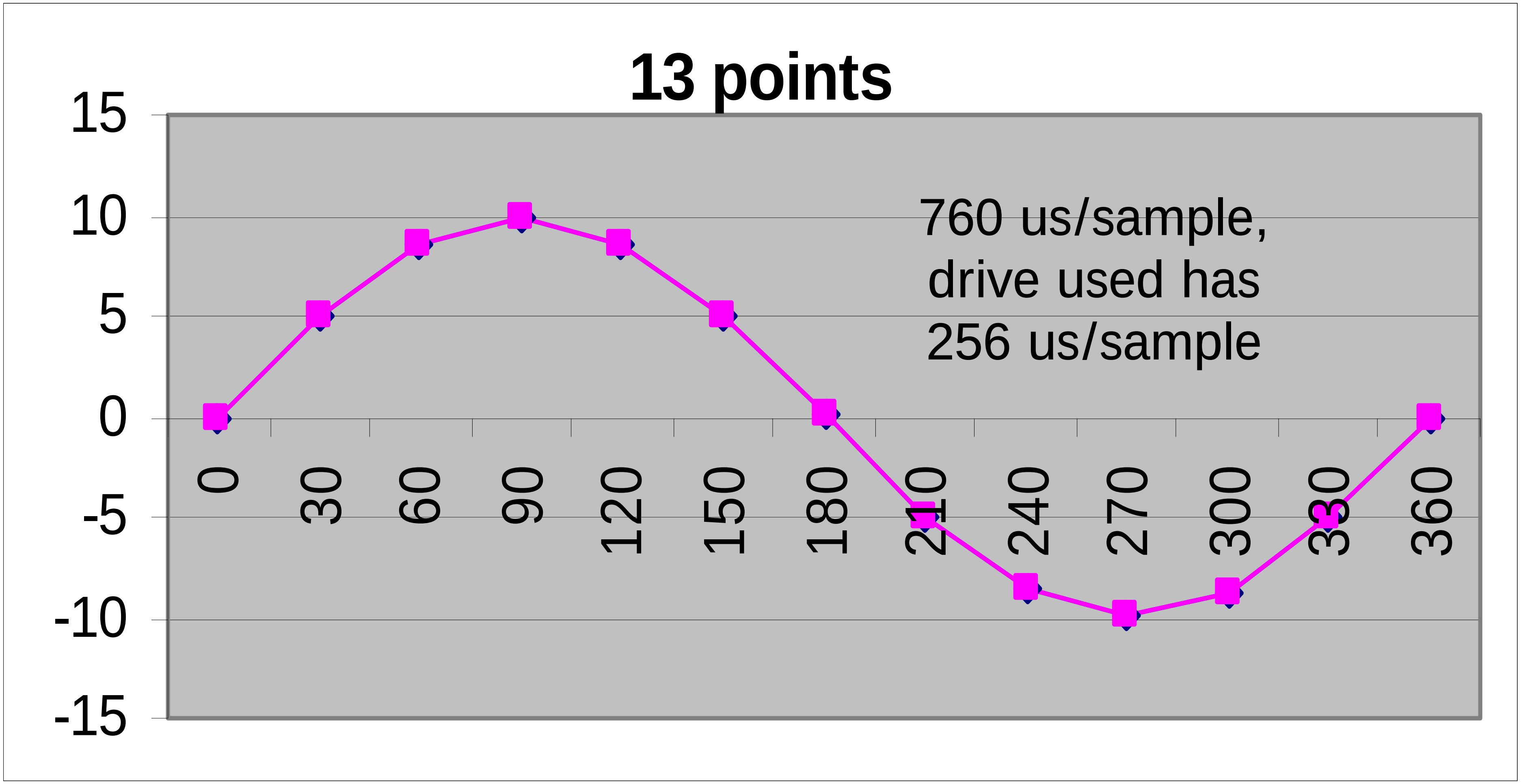

Summary and Conclusions

- Testing for torsional stress characteristics of combustion engine parts requires high accuracy and high dynamic performance
- Older mechanical/hydraulic systems are limited as to adjustability and range of operation and set up time
- Modern motor/drive systems can produce the required performance but parameters must be carefully evaluated to assure success