Better Plants®
U.S. DEPARTMENT OF ENERGY

Pumping System Assessment

Week 7:

Standard efficiency definition: $\frac{\text{Power out}}{\text{Power in}}$

Motor efficiency = $\frac{\text{Motor shaft power out}}{\text{Motor electric power in}}$

$\frac{\text{Pump fluid power out}}{\text{Pump shaft power in}}$ = Pump efficiency

Basic power relations for pumps and motors

$$\text{Pump efficiency} = \frac{\text{Fluid output power}}{\text{Shaft input power}}$$

$$\text{Motor efficiency} = \frac{\text{Shaft output power}}{\text{Electric input power}}$$

$$\text{Fluid power (hp)} = \frac{\text{Flow rate (gpm)} \times \text{Head (ft)} \times \text{specific gravity}}{3960}$$

$$\text{Fluid power (kW)} = \frac{\text{Flow rate (gpm)} \times \text{Head (ft)} \times \text{specific gravity}}{5310}$$

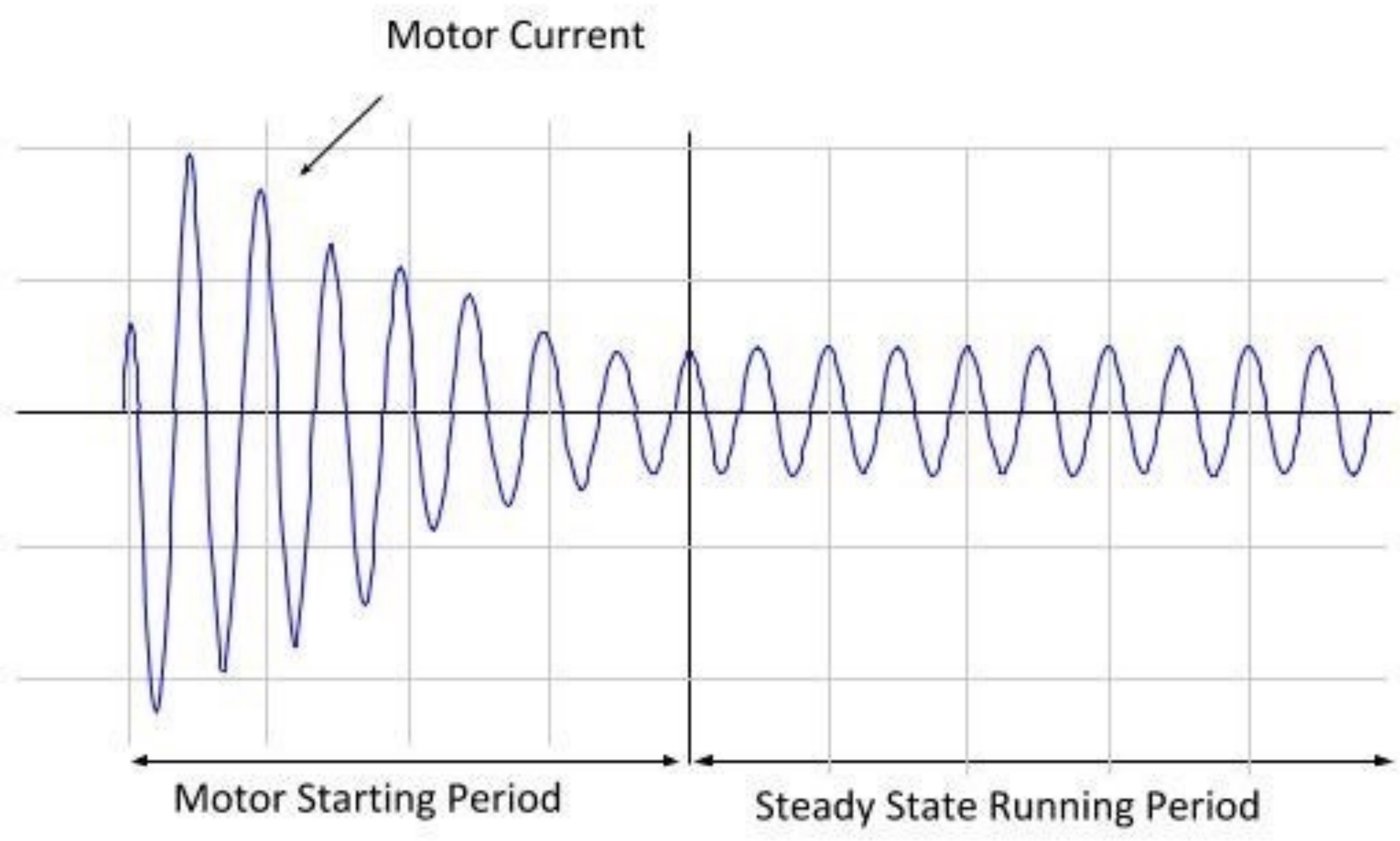
$$\text{Shaft power (hp)} = \frac{\text{Rotating speed (rpm)} \times \text{Torque (lb-ft)}}{5252}$$

$$\text{Shaft power (kW)} = \frac{\text{Rotating speed (rpm)} \times \text{Torque (lb-ft)}}{7040}$$

$$\text{Instantaneous electric power (kW)} = P_i = \frac{\sum_{p=1}^{3} V_{i,p\text{-}n} \times I_{i,p}}{1000}$$

For those who insist on being boringly practical about these sorts of things: yes, it's the number you read off of your 3-phase power meter ;-)

Electrical Starting Transients



There are several methods that minimize the electrical portion of the starting transient

- Autotransformer
- Wye-delta
- Part winding
- Solid-state
- Adjustable frequency drive

Adjustable speed drives on the motor output (such as eddy-current and fluid drives) can also reduce the mechanical-side effects, although they have minimal effect on the electrical inrush

Motor Starting Autotransformers

- Motor Starting Autotransformers reduce the inrush current by stepping down the applied voltage during the start-up operation of induction and synchronous motors.

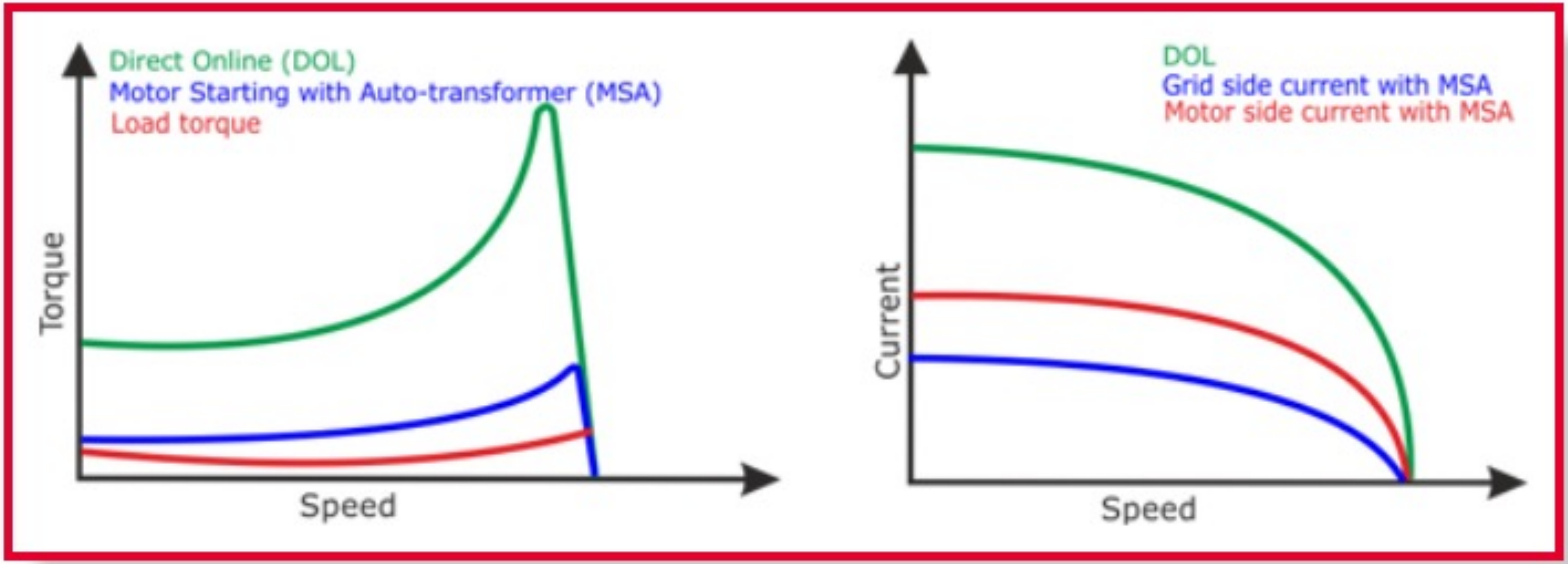
- Direct-online (DOL) starting of a motor usually generates voltage flicker and mechanical stress to the equipment. To avoid this, the motor must be started at reduced voltage, which can be achieved by using an auto-transformer. The auto-transformer greatly reduces the high starting current with moderate starting torque.

- Auto-transformers are typically designed with voltage taps of 50%, 65% and 80% of the rated voltage.

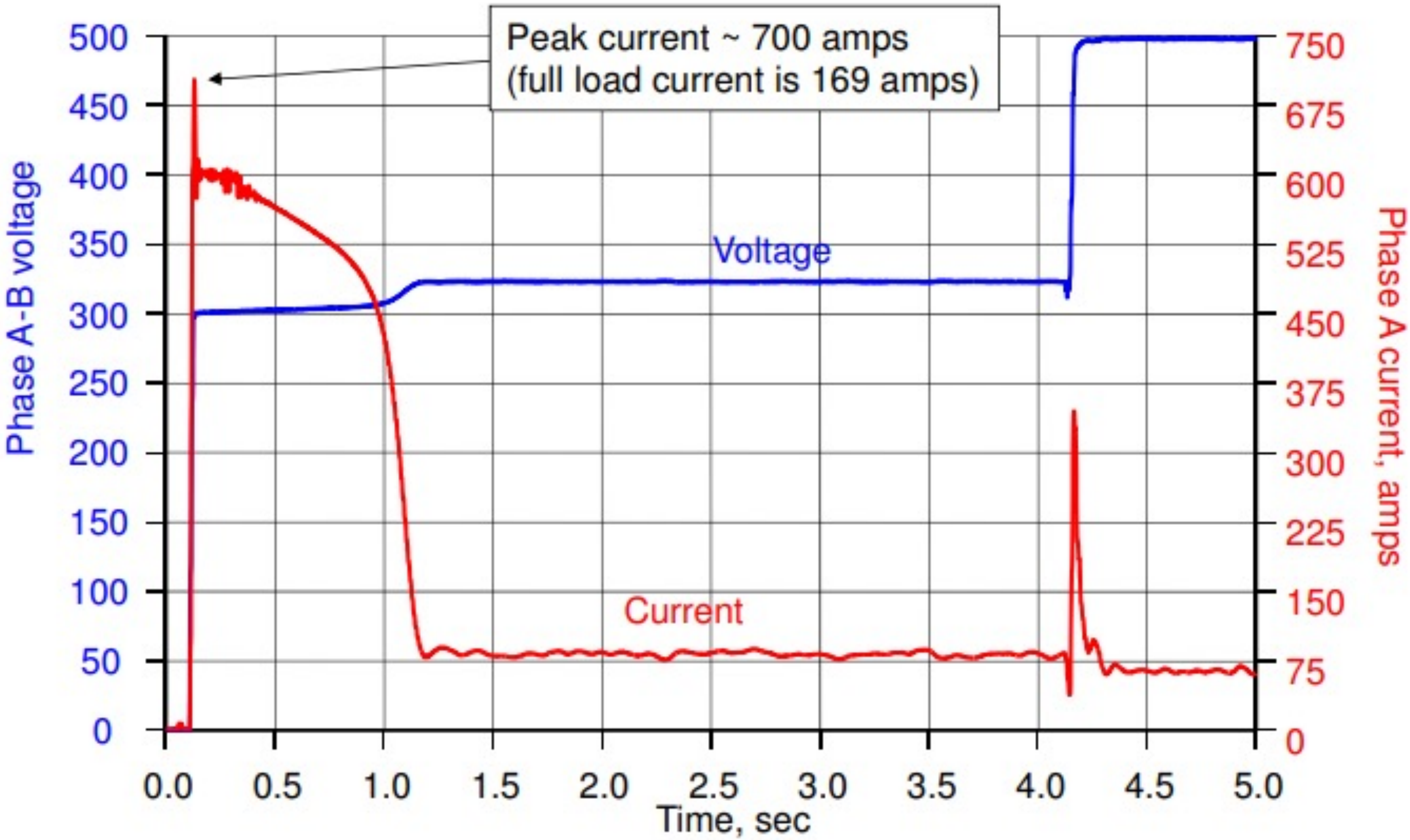
- The motor is connected to the taps of the auto-transformer during the reduced voltage starting period. With lower starting voltage, less current is drawn by the motor, which therefore develops less torque then if it were connected to the line voltage.

Autotransformer with 65% standard voltage during initial portion of motor starting

Motor Starting Autotransformers



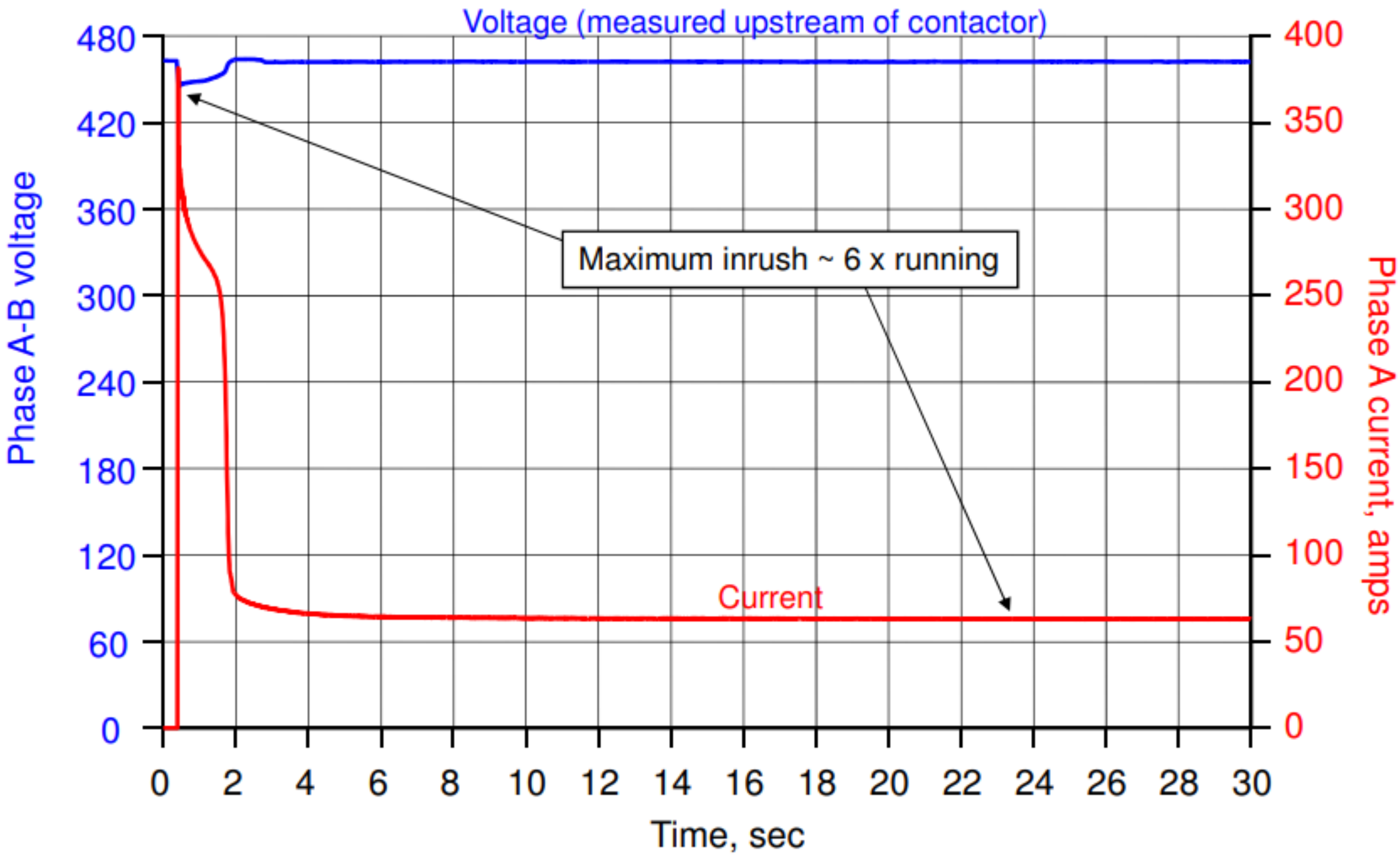
Startup transient with autotransformer (current includes motor plus capacitor)



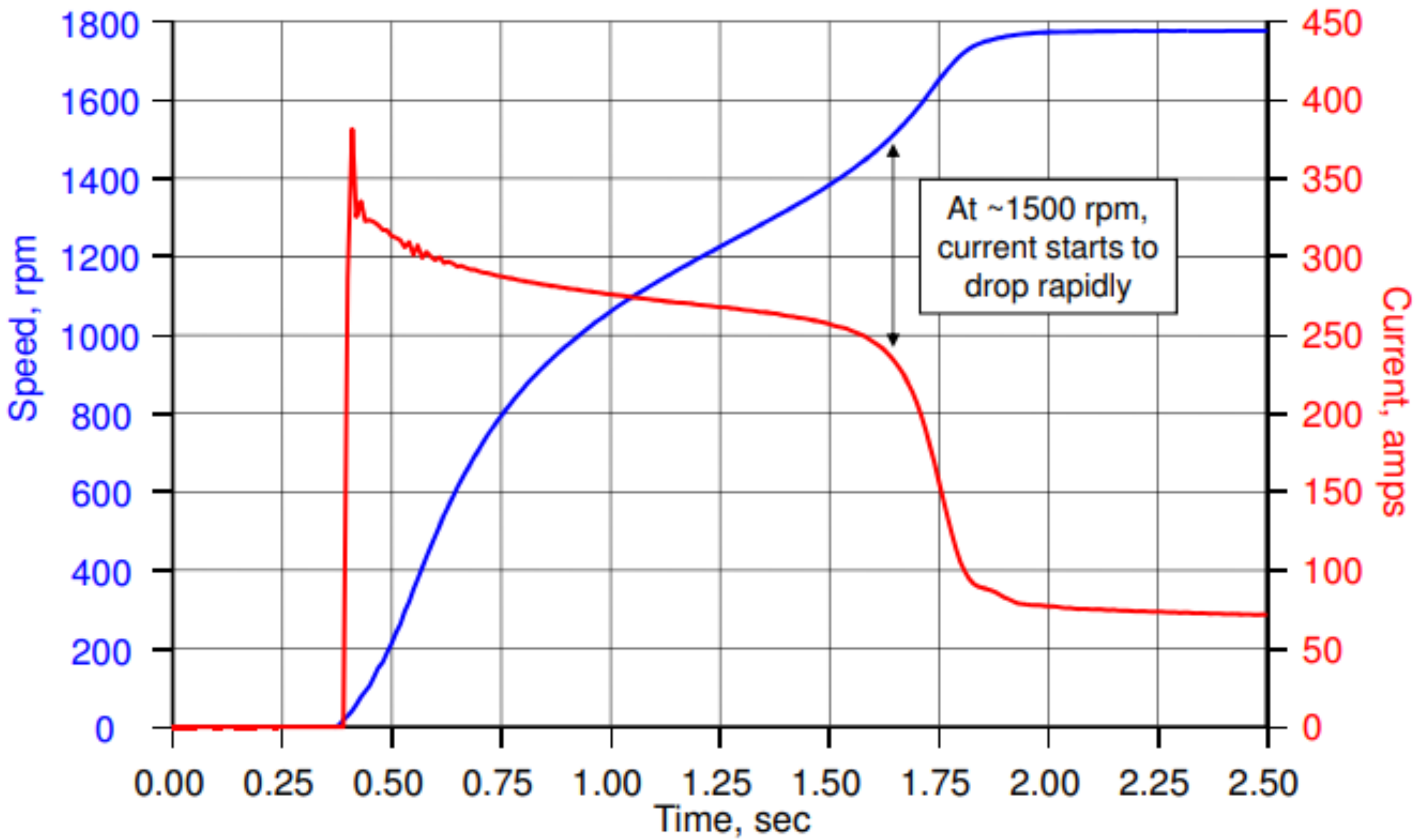
Motor: 150 hp, 4-pole

Current and voltage with direct across-the-line starting

(4-pole, 50-hp motor tested at ORNL, operated at rated load)



The electrical transient is normally dominated by inherent motor characteristics and inertia considerations

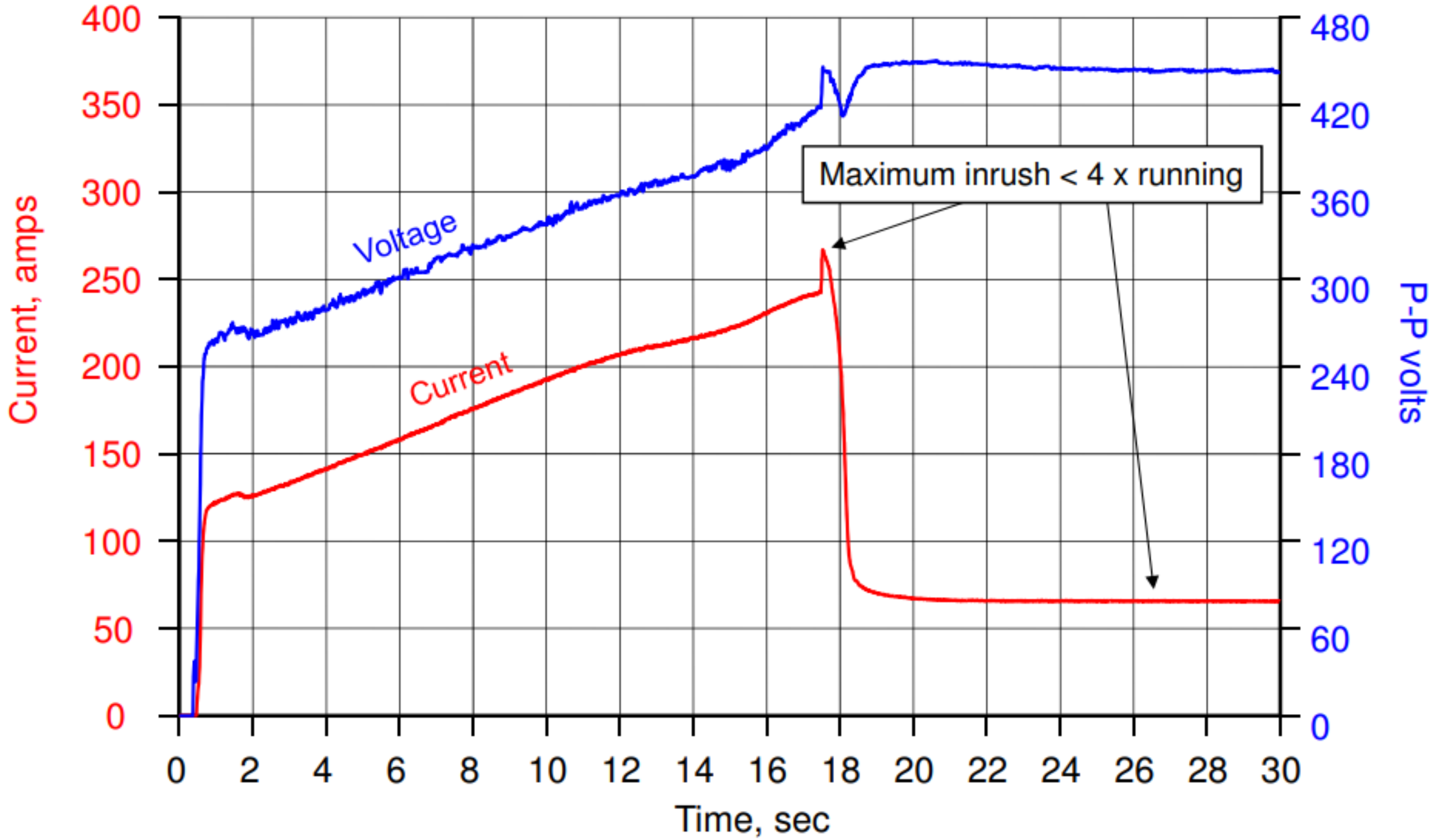


Electronic soft starters allow gradual speed ramp up/down

- Generally a positive feature from several perspectives:
  - Electrical (minimize current inrush)
  - Electromechanical (reduce magnetic distortion from high current inrush, transient radial and axial forces)
  - Fluid (minimize or eliminate startup/shutdown pressure transients & water hammer)

Current and voltage with solid-state soft starter

(same ORNL motor and load condition as shown in earlier slide)

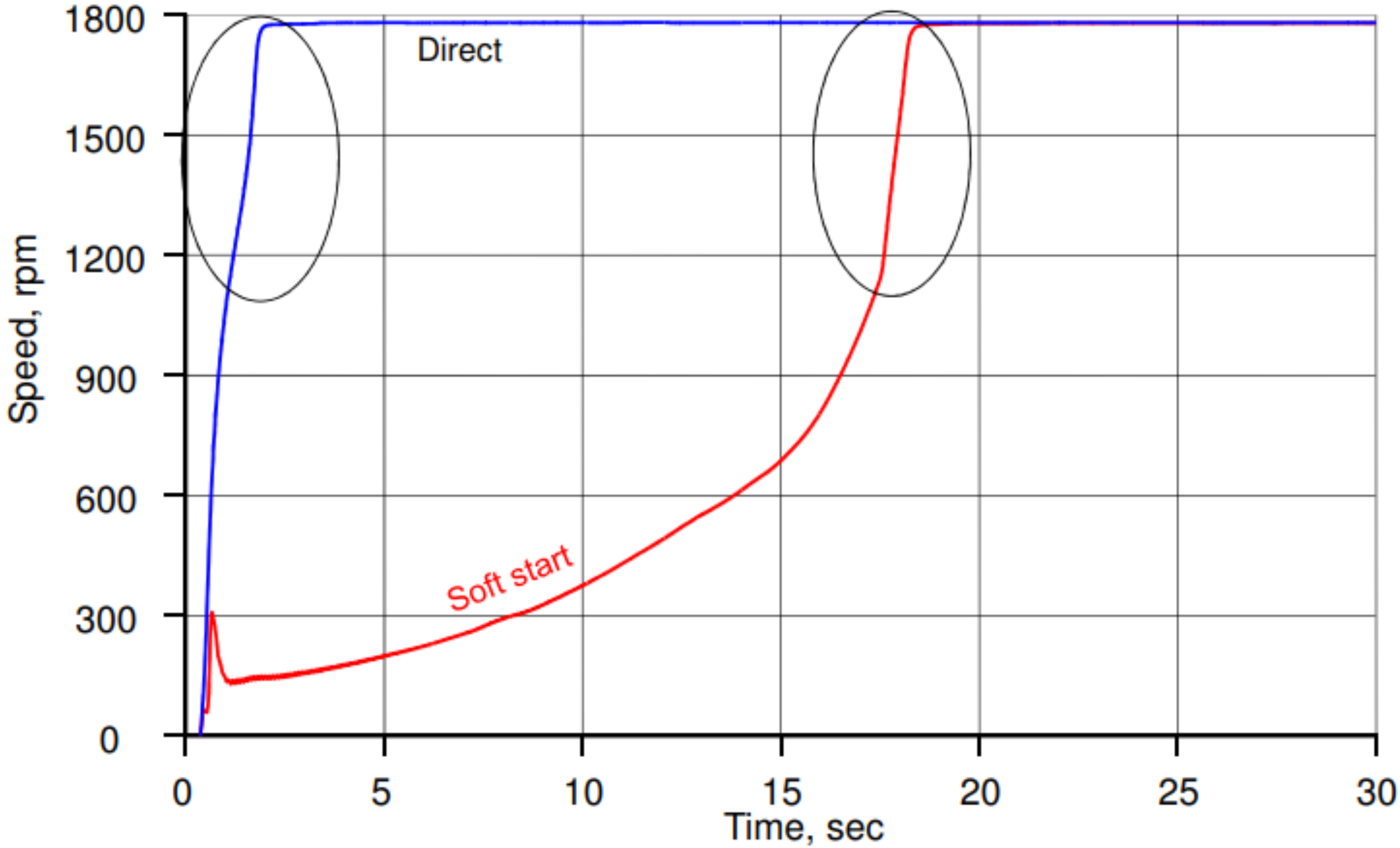


Water Hammer

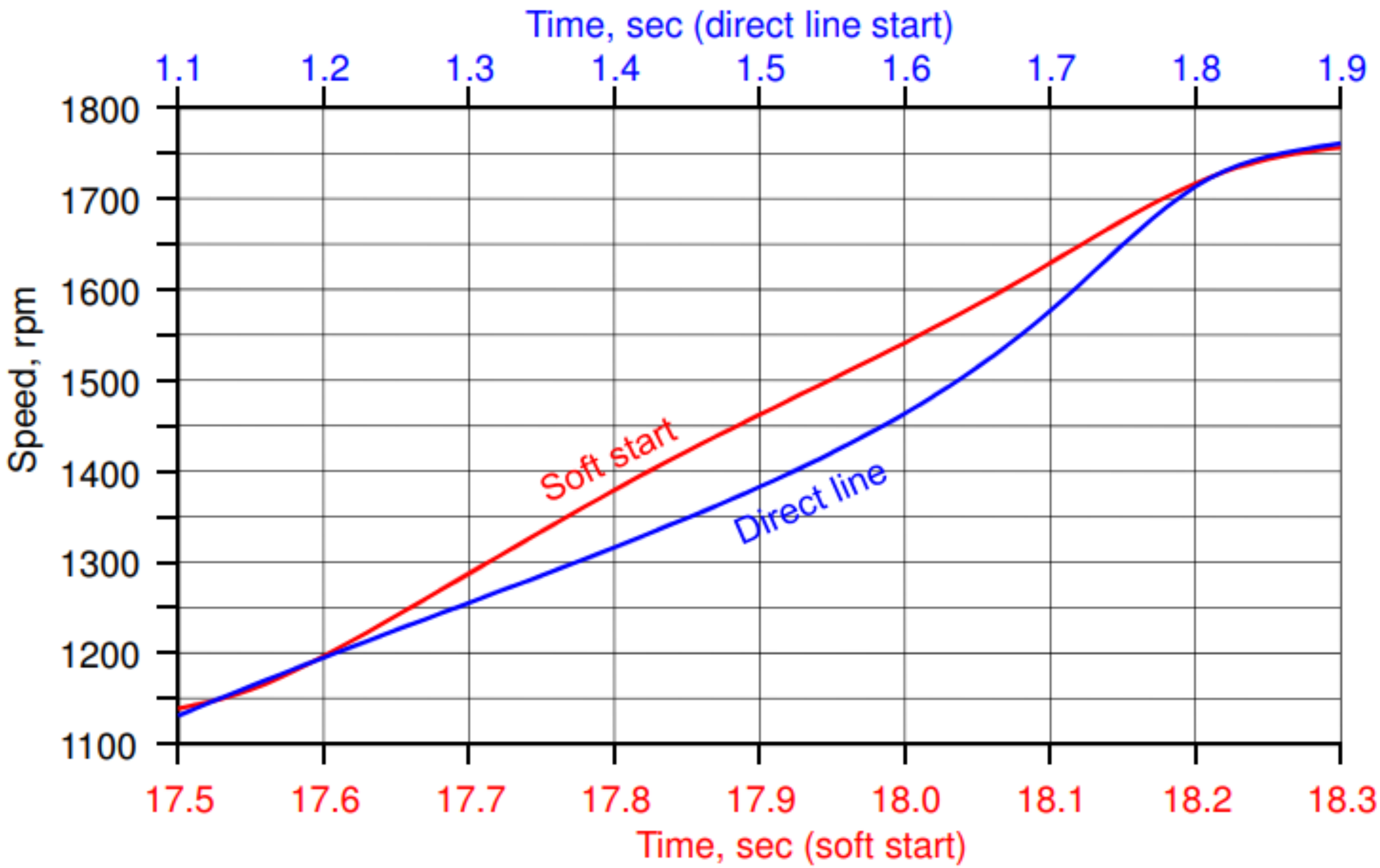
- Water Hammer is a phenomenon that can occur in any piping system where valves are used to control the flow of liquids. Water hammer is the result of a pressure surge, or high-pressure shockwave that propagates through a piping system when a fluid in motion is forced to change direction or stop abruptly. This shockwave is also commonly referred to as a hydraulic shock or hydraulic surge and may be characterized by a marked banging or knocking sound on the pipes immediately after shutoff.

- Water hammer can occur when an open valve suddenly closes, causing the water to slam into it, or when a pump suddenly shuts down and the flow reverses direction back to the pump. Since water is incompressible, the impact of the water results in a shock wave that propagates at the speed of sound between the valve and the next elbow in the piping system or within the column of water after the pump.

Important: proper ramp control is critical to fluid side response



In a fluid system with moderate-to-high static head, the fluid transient for a soft start ramp would be essentially identical to the direct line start



(0.8 seconds time duration on both the upper and lower axis)

How to choose between a VFD and soft starter

Variable frequency drive applications

VFDs are used in applications where:

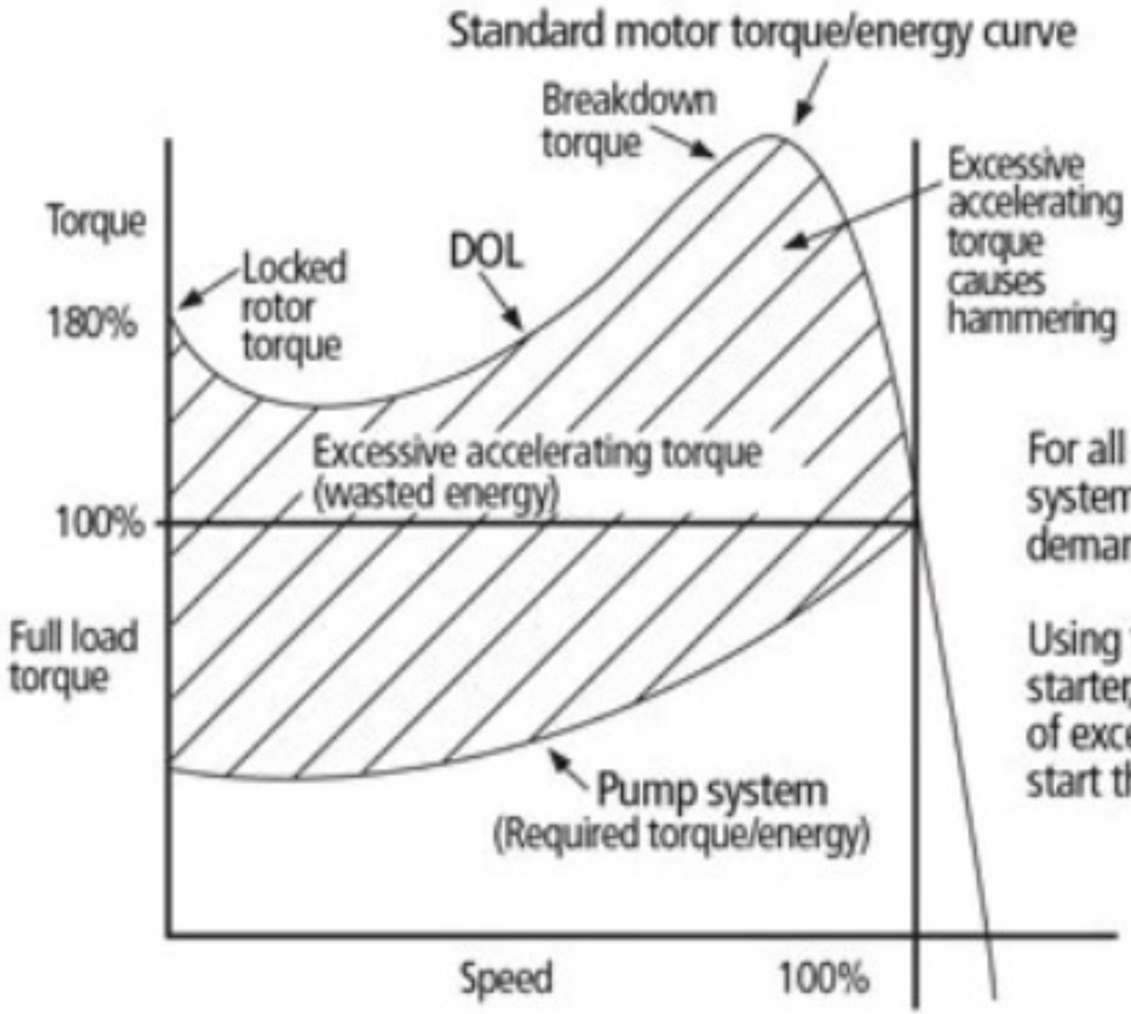
- Complete speed control is required
- Energy savings is a goal
- Custom control is needed
- Starting current needs to be reduced while maintaining high starting torque

Soft starter applications

Soft starters are used in applications where:

- Speed and torque control are required only during startup (and stop if equipped with soft stop)
- Reducing large startup inrush currents associated with a large motor is required
- The mechanical system requires a gentle start to relieve torque spikes and tension associated with normal startup (for example, conveyors, belt-driven systems, gears, and so on)
- Pumps are used to eliminate pressure surges caused in piping systems when fluid changes direction rapidly

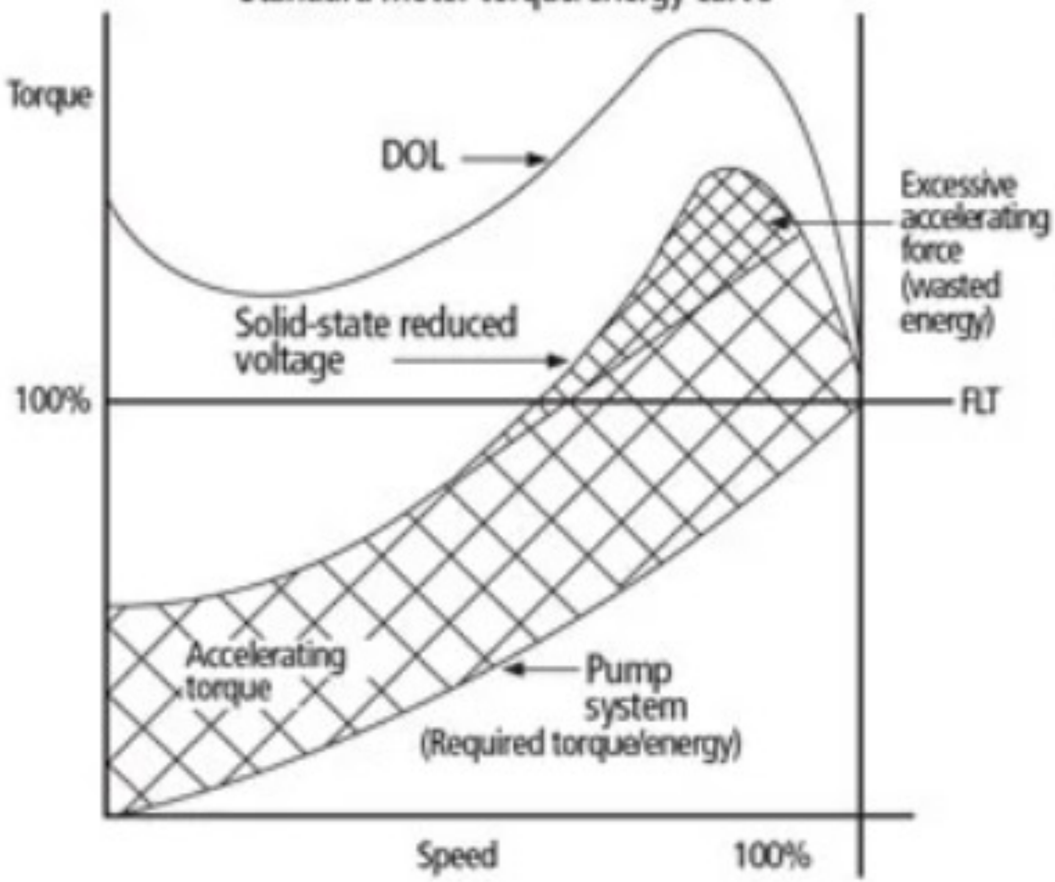
DOL pump starting



For all plots, the pump system line is the demanded load torque.

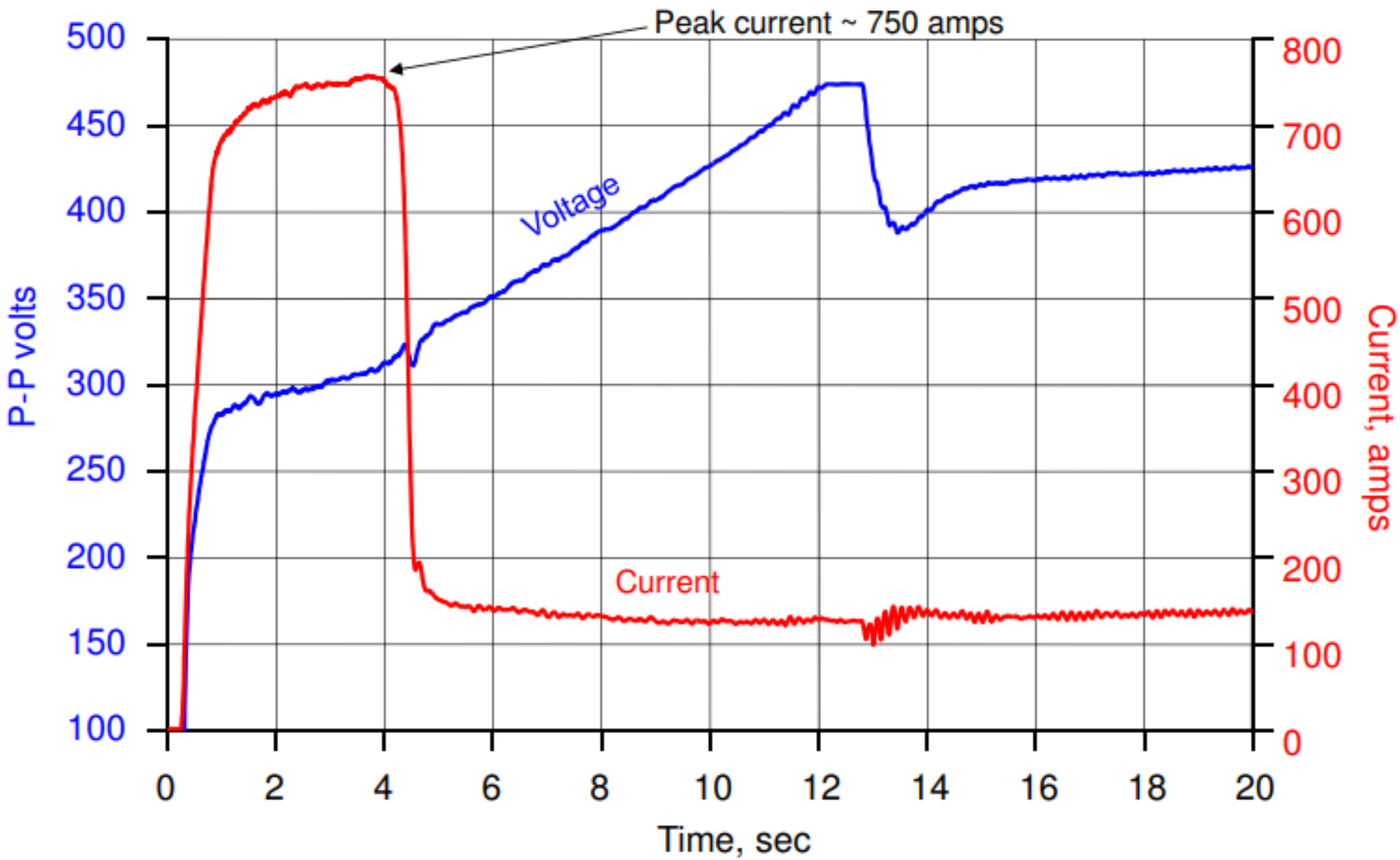
Using the standard DOL starter, note the amount of excess energy used to start the pump.

Soft start pump starting

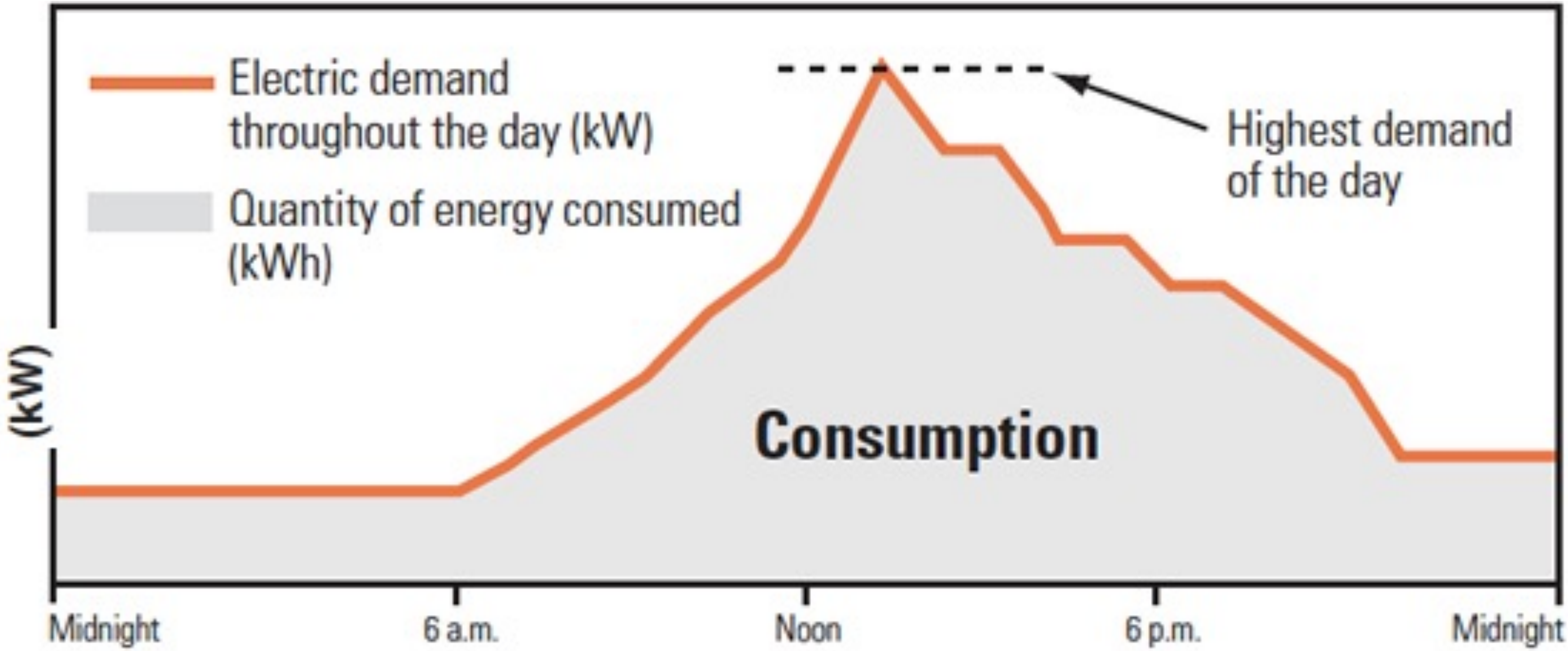


Soft start reduces the overall energy required to start the load although some excess torque remains.

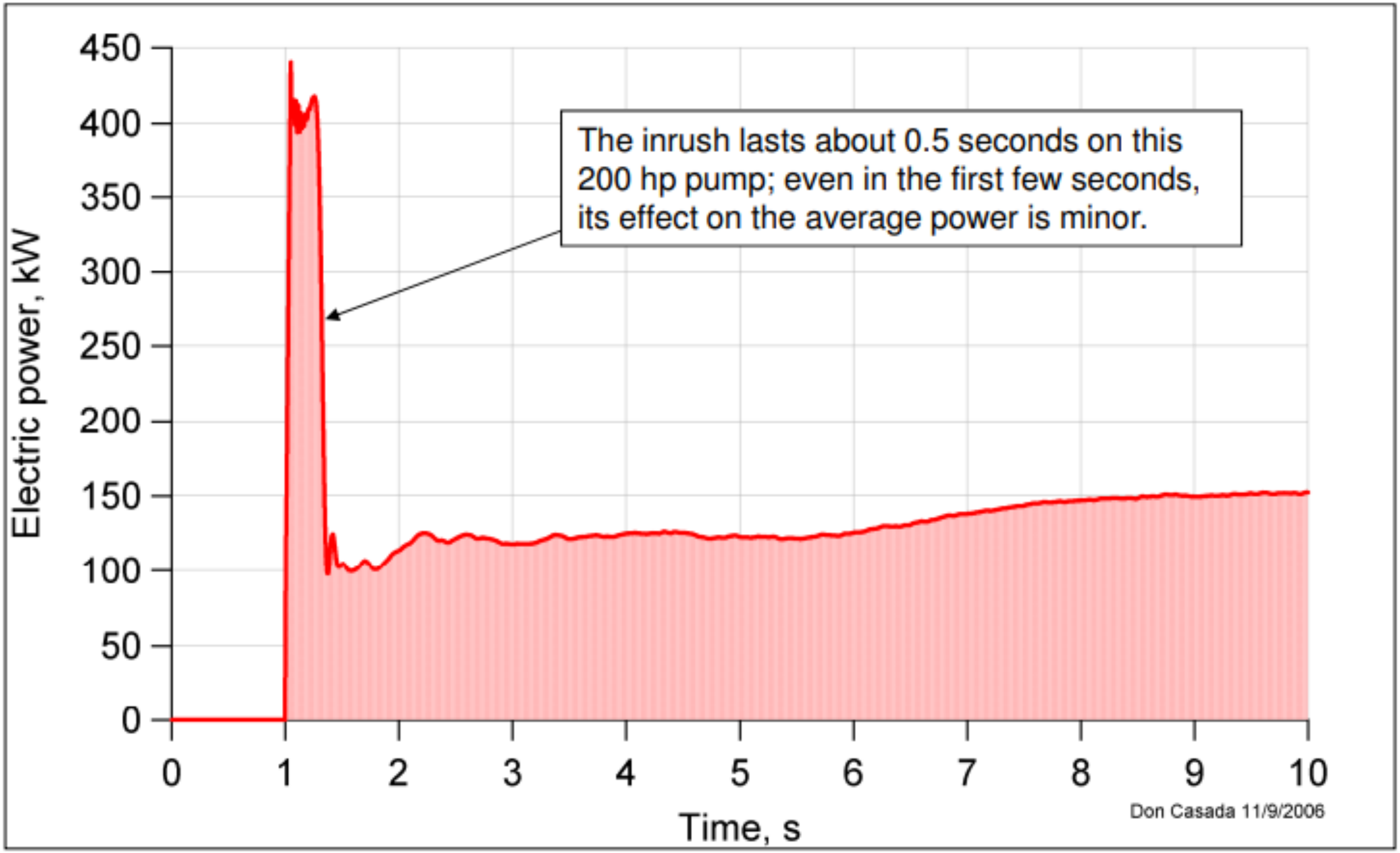
Startup transient for 250 hp, 6-pole motor with soft starter



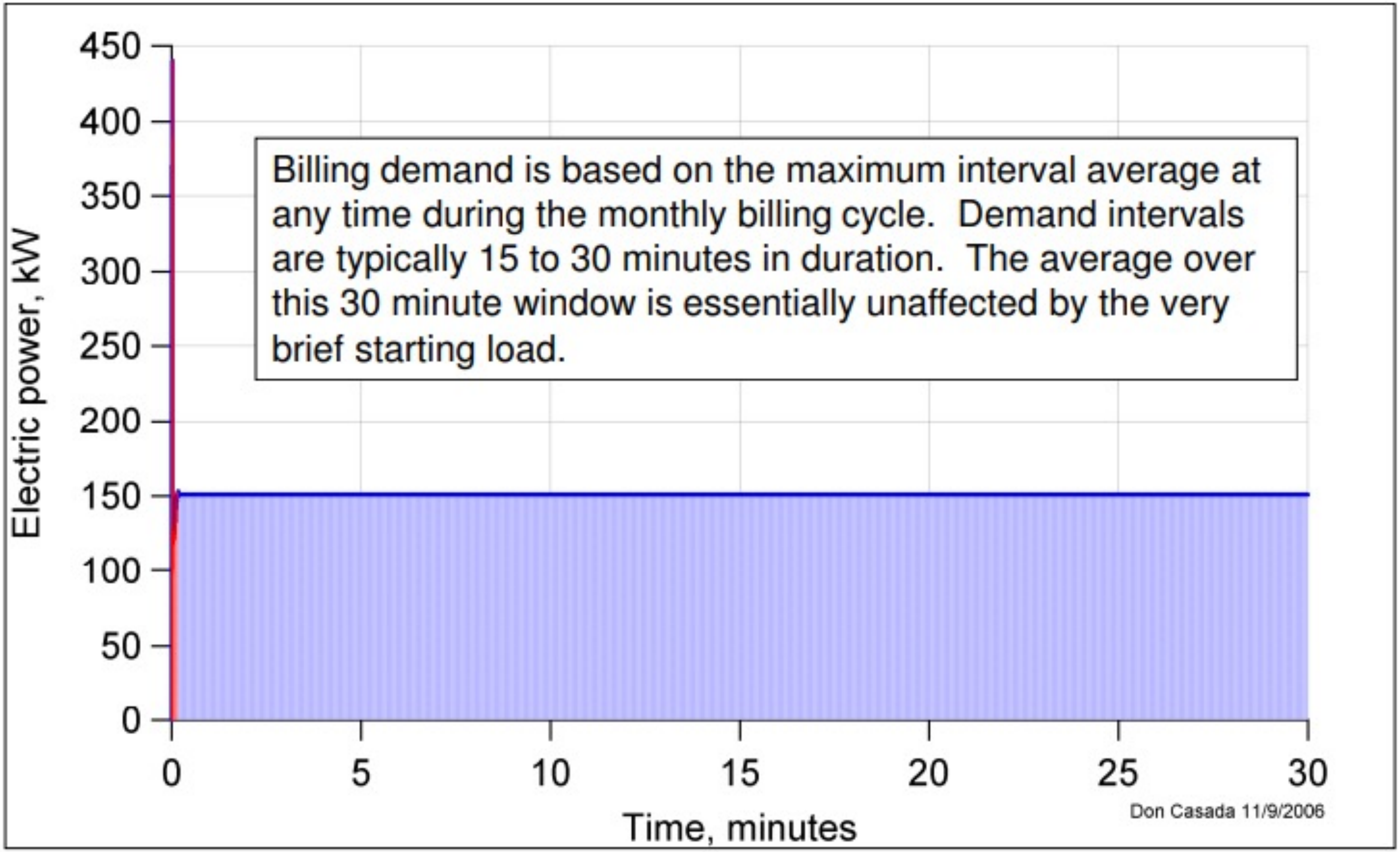
Startup transient impact on billing demand



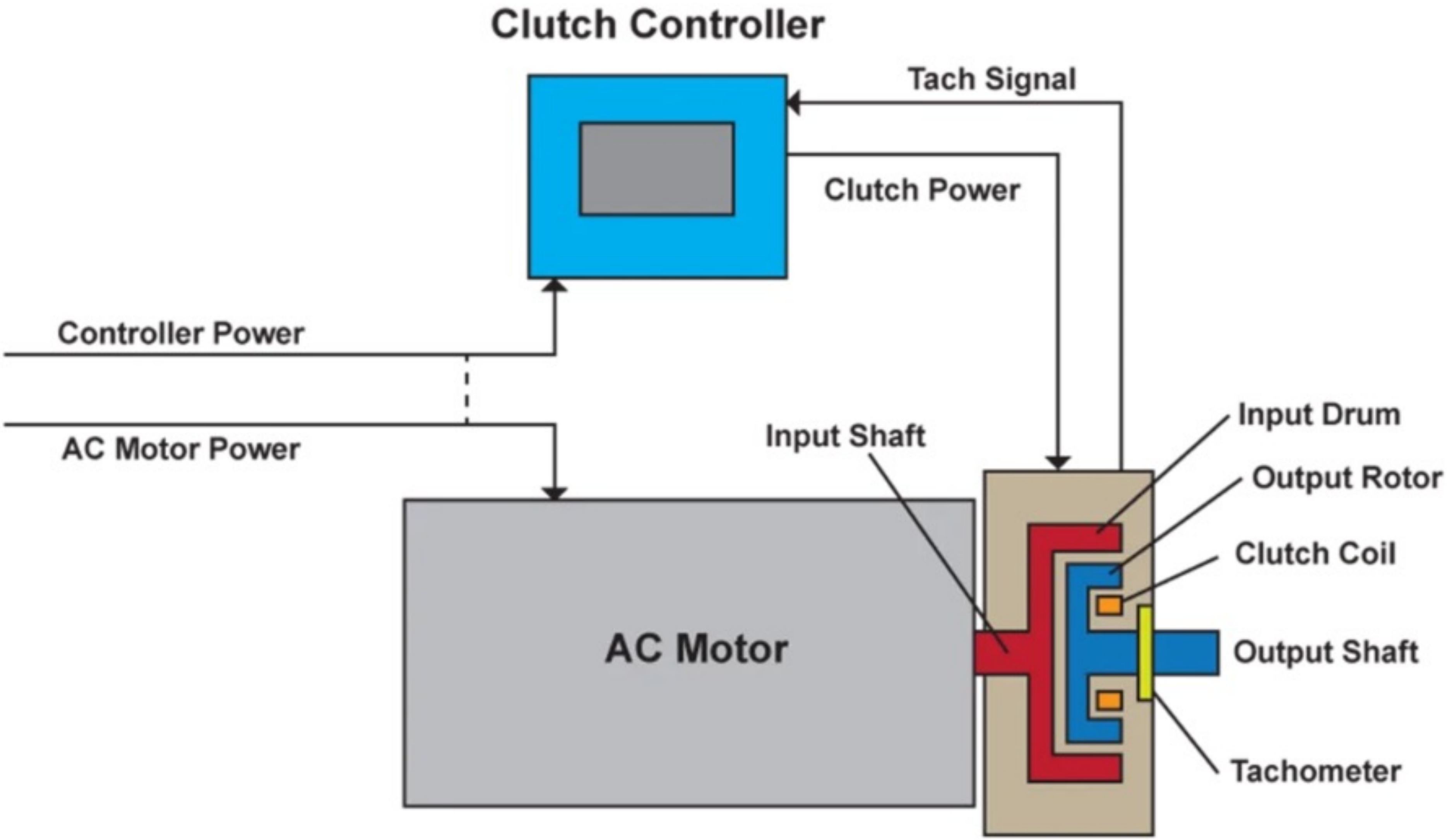
Regardless of the motor type: the starting inrush is very minor with respect to demand charges



Over the 30 minute demand window, it is hard to detect the impact of the pump startup



Eddy current adjustable speed drive



Eddy current adjustable speed drive

- Variable frequency drives (VFDs) and DC drives operate by electronically altering the input power to control the speed of the motor. Eddy current drives, also known generically as magnetic drives, eddy current clutches or magnetic clutches are driven at a constant speed by an AC motor and utilize a simple electro-magnetic device to control torque and speed to the driven load.
- In a typical horizontal configuration, an ordinary induction motor is mounted beside the eddy current drive. The eddy current drive is built within a stationary frame and a flange and shaft like that of the motor. Within the frame are two concentric rotating members: The drum, shown in red, and the magnetic rotor shown in blue.
- The drum is a cylinder of magnetically permeable steel coupled directly to the motor shaft, and rotates at pretty much constant speed, determined by the speed of the motor.

Eddy current adjustable speed drive

- The adjustable speed magnetic rotor is mounted concentrically within the drum, and is separated by bearings, which maintain an air gap between the i.d. of the drum and the o.d. of the magnet. The outer surface of the magnet consists of a series of magnetic poles having alternating north and south polarity which are magnetized at varying strength by a low-power DC current, referred to as excitation.

- The excitation current flows to a coil which induces magnetic flux to the pole pieces. As the rotating drum passes through the magnetic flux field in the air gap, a pattern of eddy currents is established in the drum's steel. These currents in turn establish a magnetic field of their own, causing an exchange of torque from the drum to the magnetic rotor.

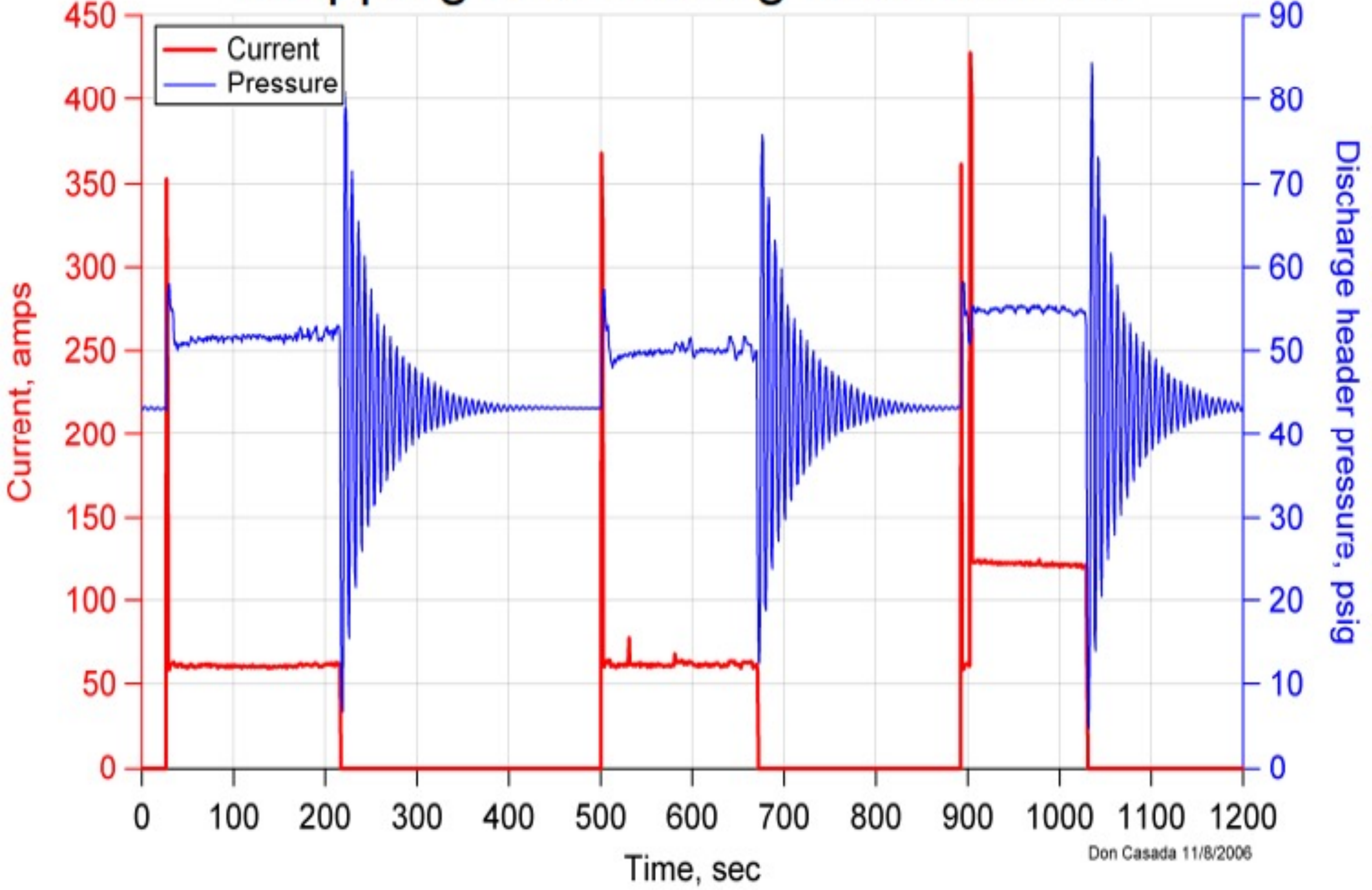
Eddy current adjustable speed drive

- The available torque is proportional to the excitation current flowing in the magnet's coils. Thus, by increasing or decreasing this excitation current, speed is controlled. A tachometer-generator device is provided for feedback to the controller, and for external reporting to a visible meter or central control system.

More simplistic water hammer considerations

- F=ma
- Hard and soft fluids, hard and soft pipes
- Gradual is (usually) good, but you need timin', a tick a tick a tick a timin'.....
- Interesting times can be had:
  - Flow reversal after pump shutdown with an erratic (e.g., sticky) check valve
  - Pump start in an unfilled line
  - Column separation (and other vapor pocket circumstances)
  - Demonstrations

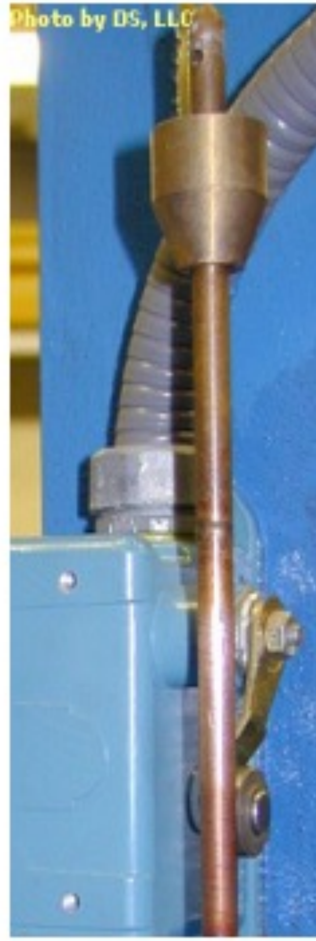
Water hammer events are related to sudden stopping of a moving fluid column



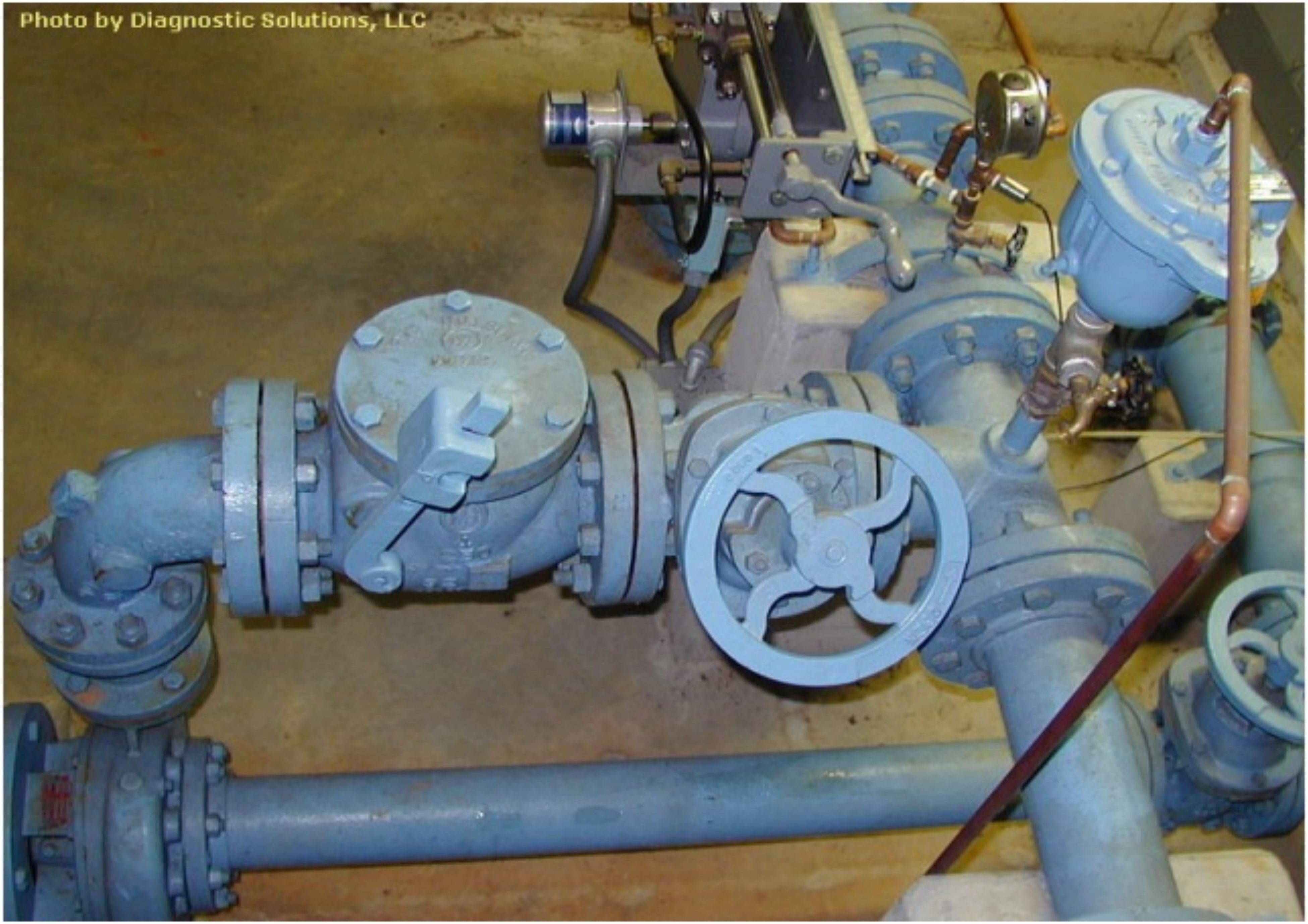
Some methods of minimizing or avoiding surge and water hammer transients

- Don't have static head in your system ;-)
- Adjustable speed drives & soft starters (and stoppers)
- Startup/shutdown control valves (automatic or manual)
- Well-selected check valves
- Air release valves/vacuum breakers

Air release valve, pump start/stop control valve



Weighted arm swing check, air release



Combination water-operated control/check valve


The End