HAZARDS OF REVERSE PUMP ROTATION

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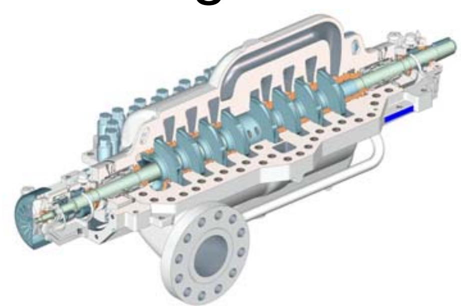
PROBLEM SYNOPSIS

- High pressure water flood injection pump with customer concern for potential reverse rotation in the event of a discharge check valve failure. Previous valve failure had caused some pump damage.



- Pump is an API BB3, 10 stage

- Pump is driven at a constant speed by 1500 BHP horizontal induction motor

- 2 pumps – main and standby piped in parallel arrangement

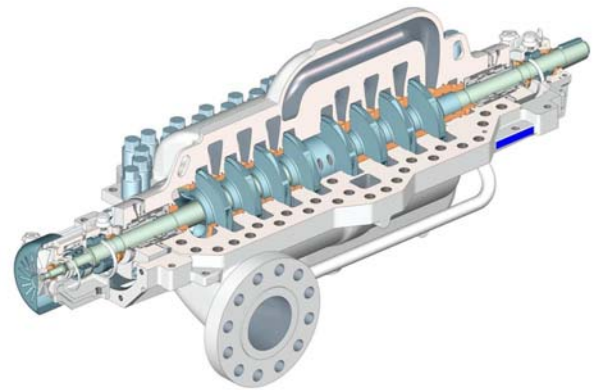
Requested

Questions to be answered are:

- In the event of a check valve failure will the pump and motor realize reverse rotation?

- Will reverse rotation damage pump, motor, seals, coupling, etc?

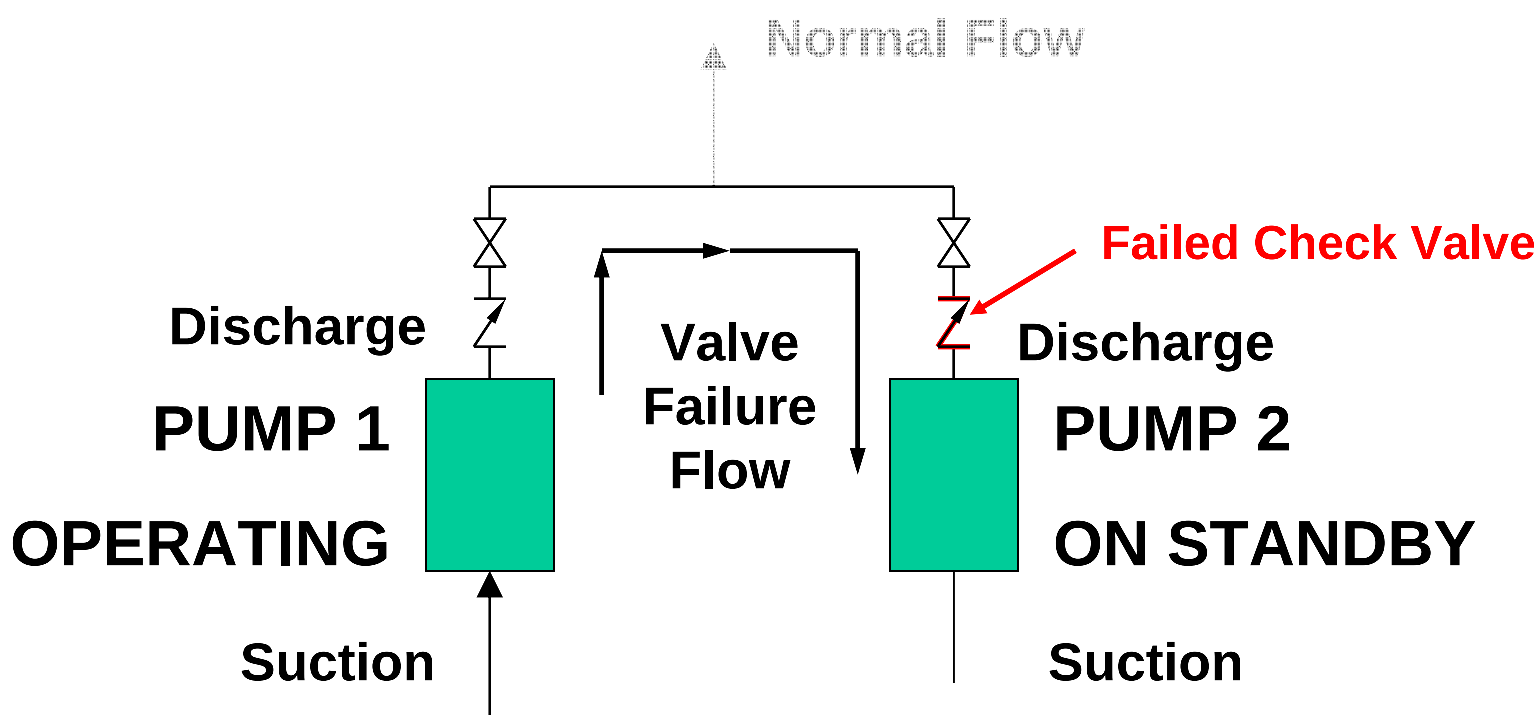
Considerations



- System configuration
- Available reverse flow rate at pump
- Head drop expected across the pump
- Break away torque and running resistance of the pump/motor train

Considerations

System configuration



Considerations

Available reverse flow rate to the pump

Head drop expected across the pump

BEST EFFICIENCY

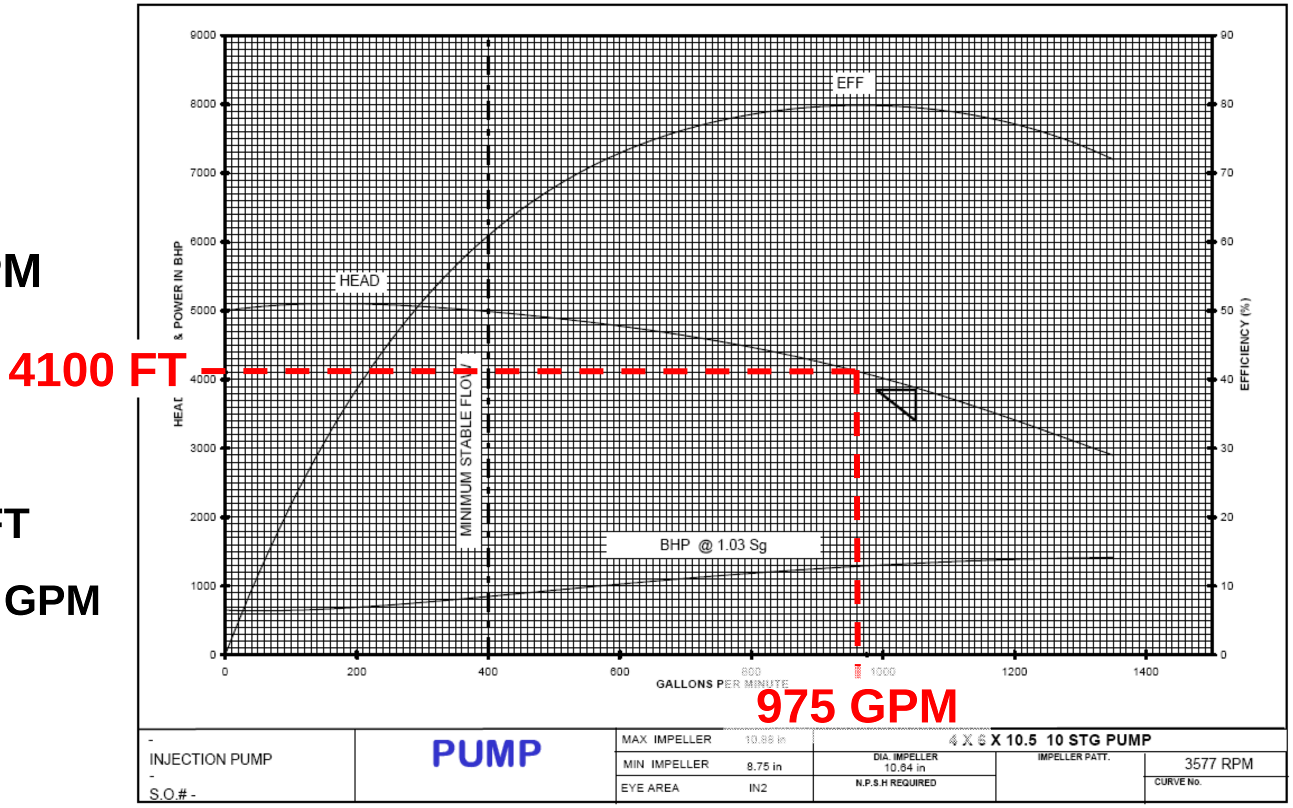
HEAD – 4100 FT

CAPACITY – 975 GPM

FULL RANGE

HEAD – 5000 TO 3000 FT

CAPACITY – 0 TO 1350 GPM



PUMPS 1 AND 2 NORMAL PERFORMANCE

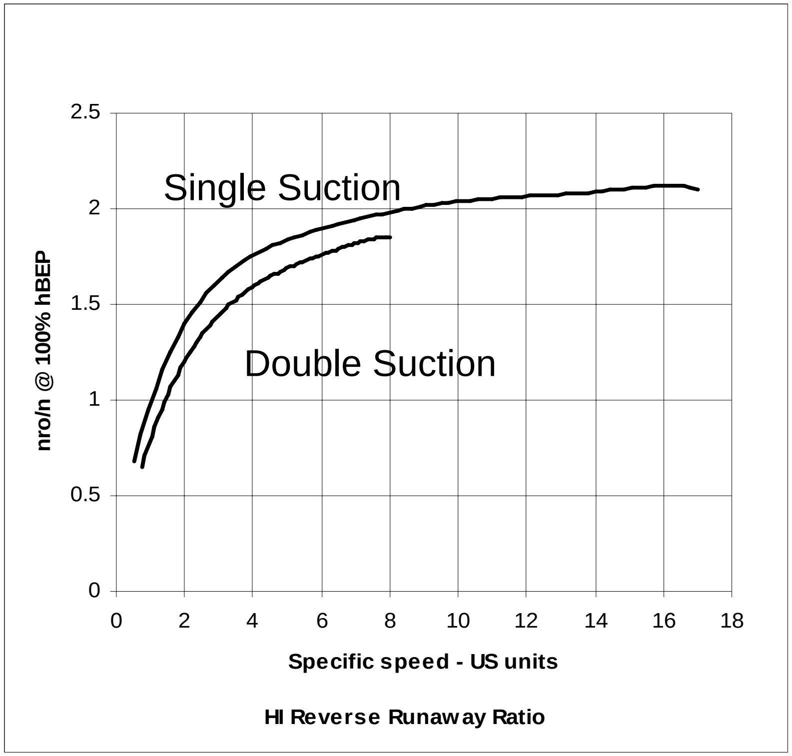
Initial Checks

- **Will the pump rotate in reverse direction?**

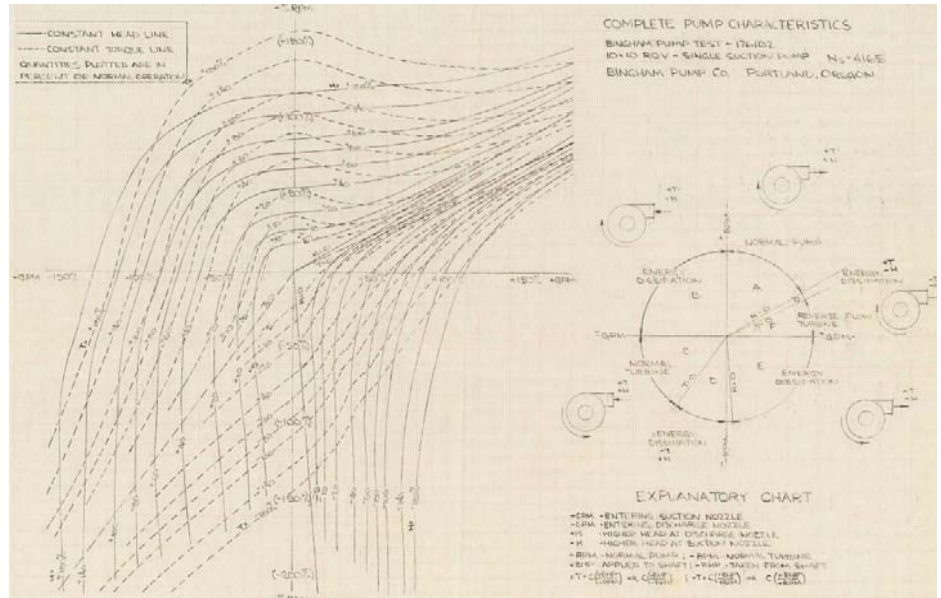
  Consider the factors.

  - **Seal drag**
  - **Bearings**
  - **Rotor inertia**
  - **Driver inertia**

TOOLS



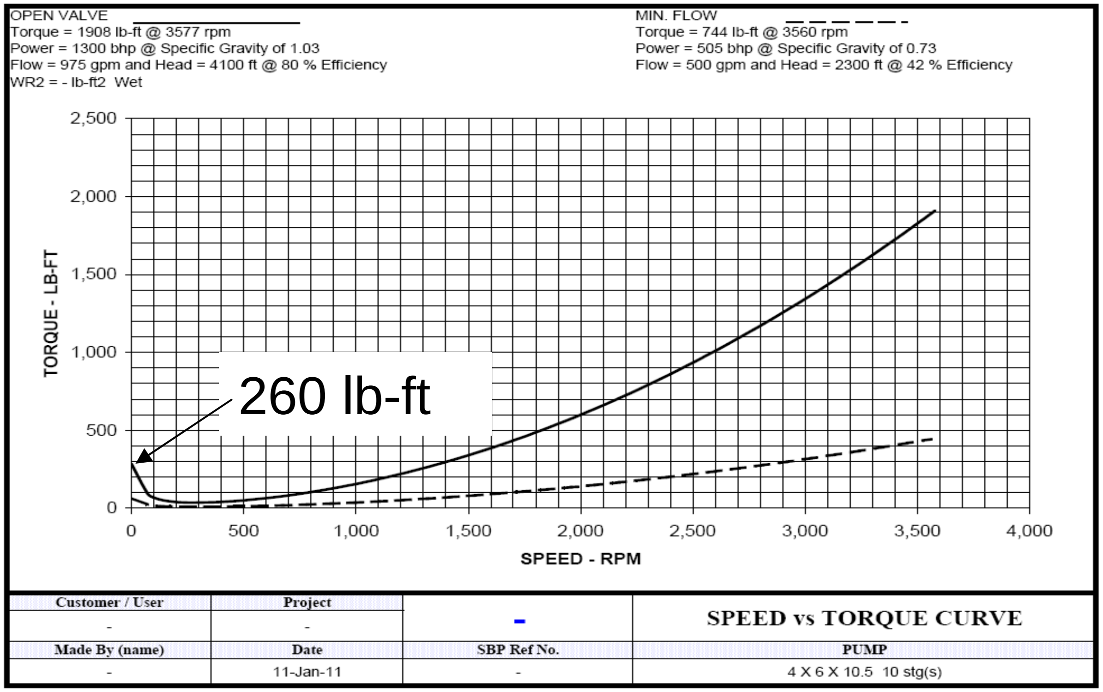
Hydraulic Institute provides guidance using a ratio



Pump OEMs sometimes provide four quadrant curves also known as Knapp or total performance curves

See publications by A. J. Stepanoff and R.T. Knapp for additional information.

Initial Checks



Case study pump Speed/Torque curve shows 260 lb-ft breakaway.

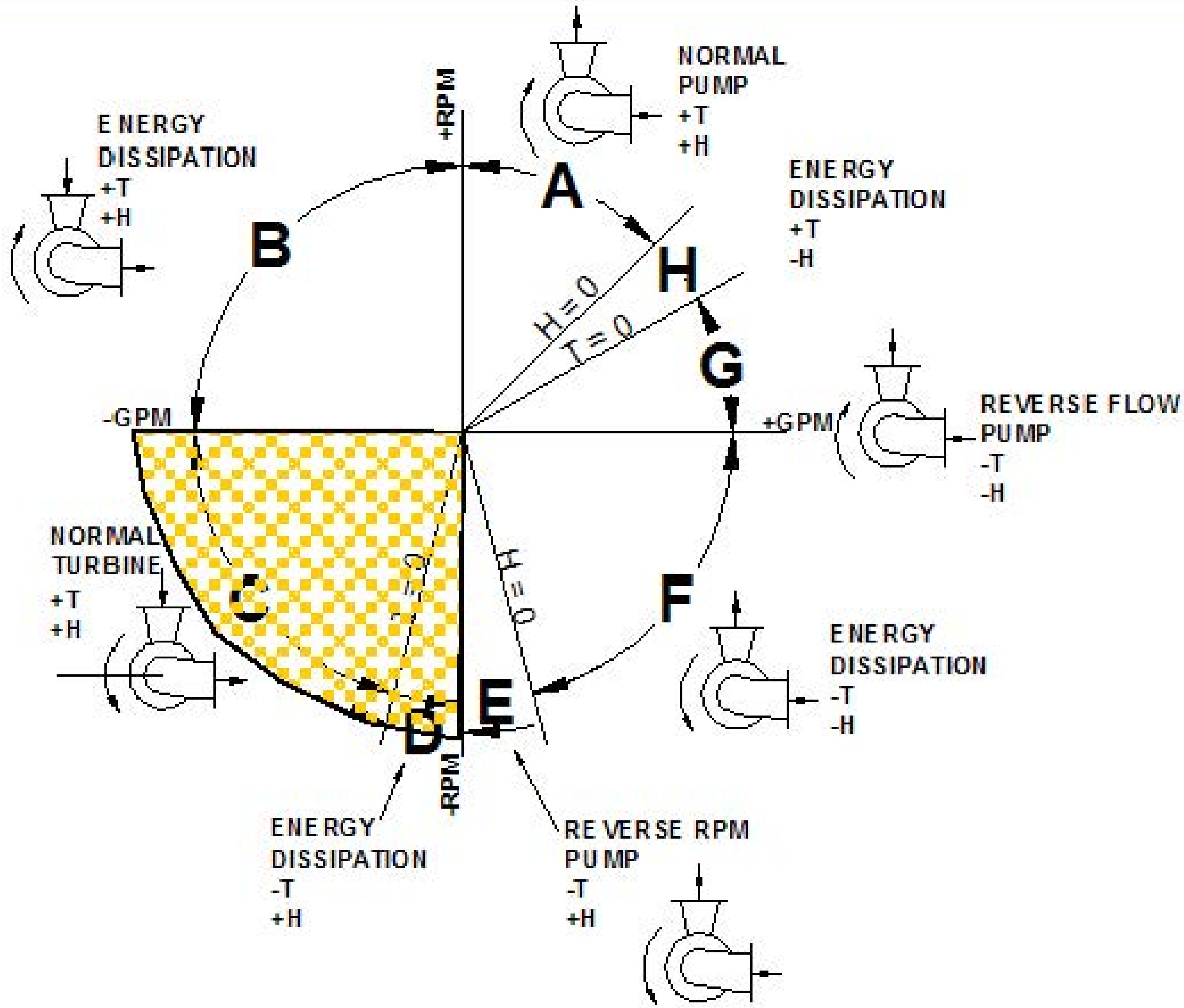
Assume motor breakaway at 50% of pump for a total of 390 lb-ft

Pump full speed power per performance curve = 1300 BHP @ 3577 RPM

100% torque = 5252*1300/3577 = 1909 lb-ft

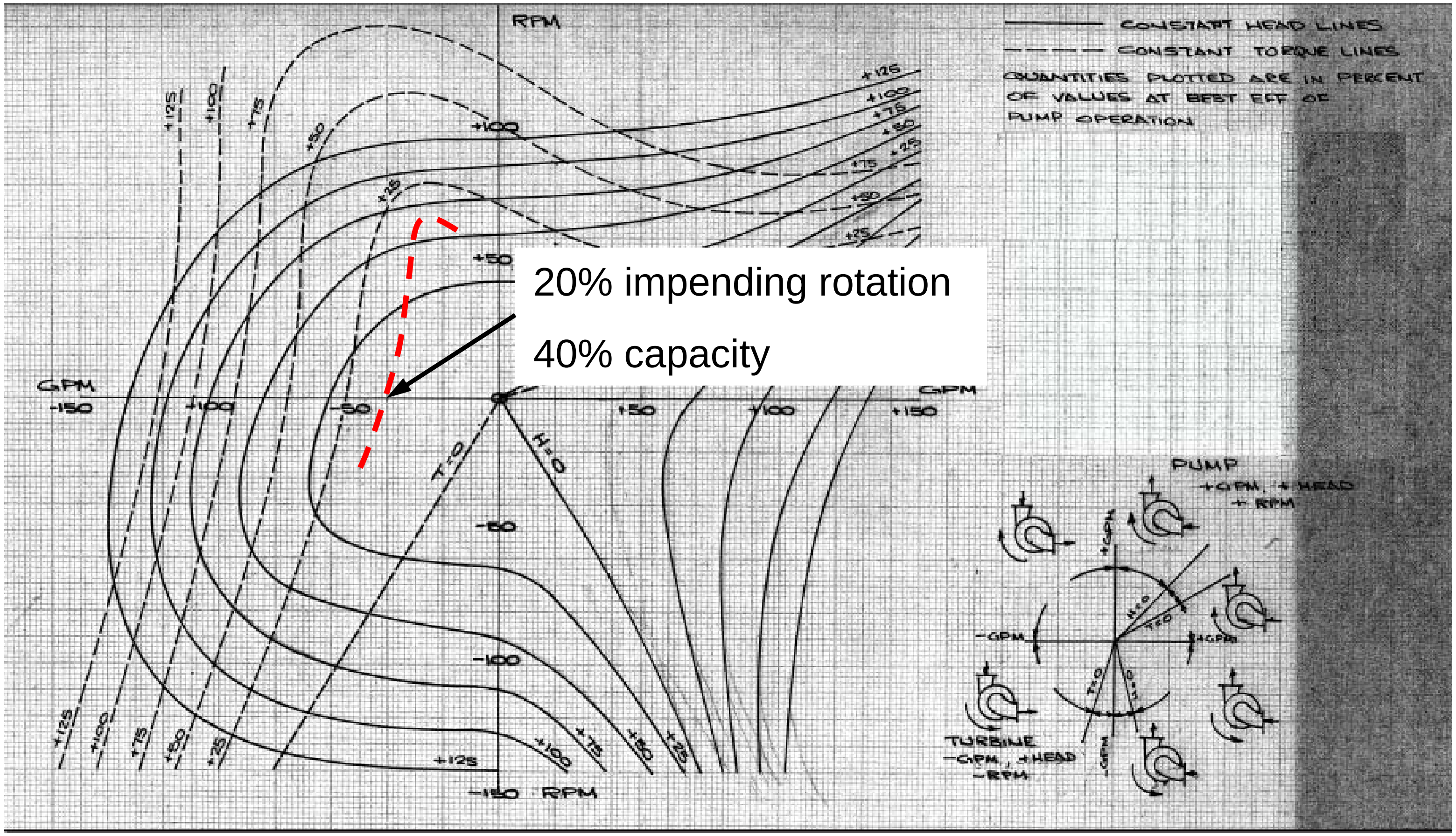
Breakaway torque = 20% of full load torque.

Four Quadrant



PUMP CIRCLE DIAGRAM

Impending Rotation

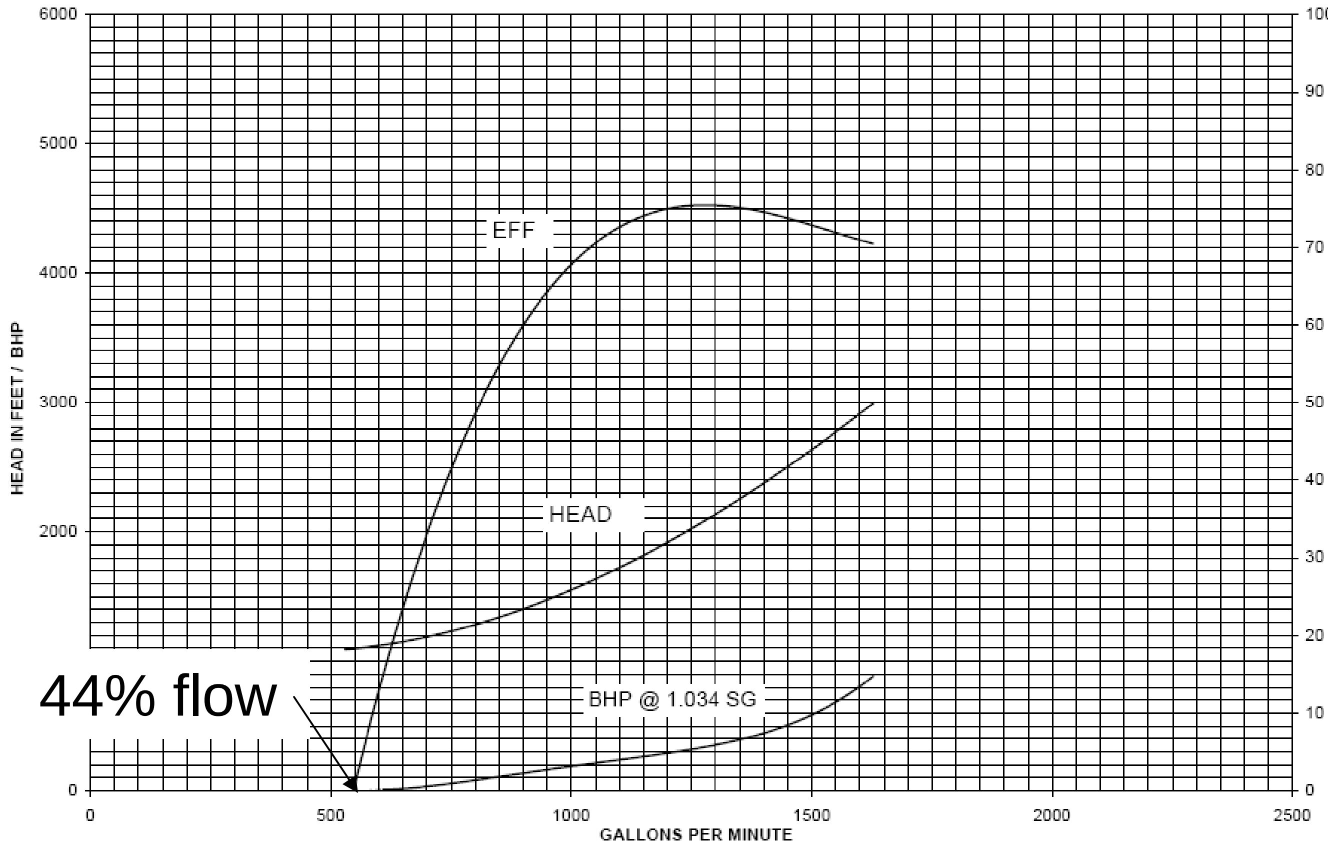


Estimate 20% torque line on Quadrant curve and plot on the zero speed line.

In this case we can see that the flow rate will be at about 40% (390 gpm) in the worst case before the pump will start to rotate.

PERFORMANCE

40% looks reasonable when we look and a typical hydraulic turbine curve (Pump running in reverse)

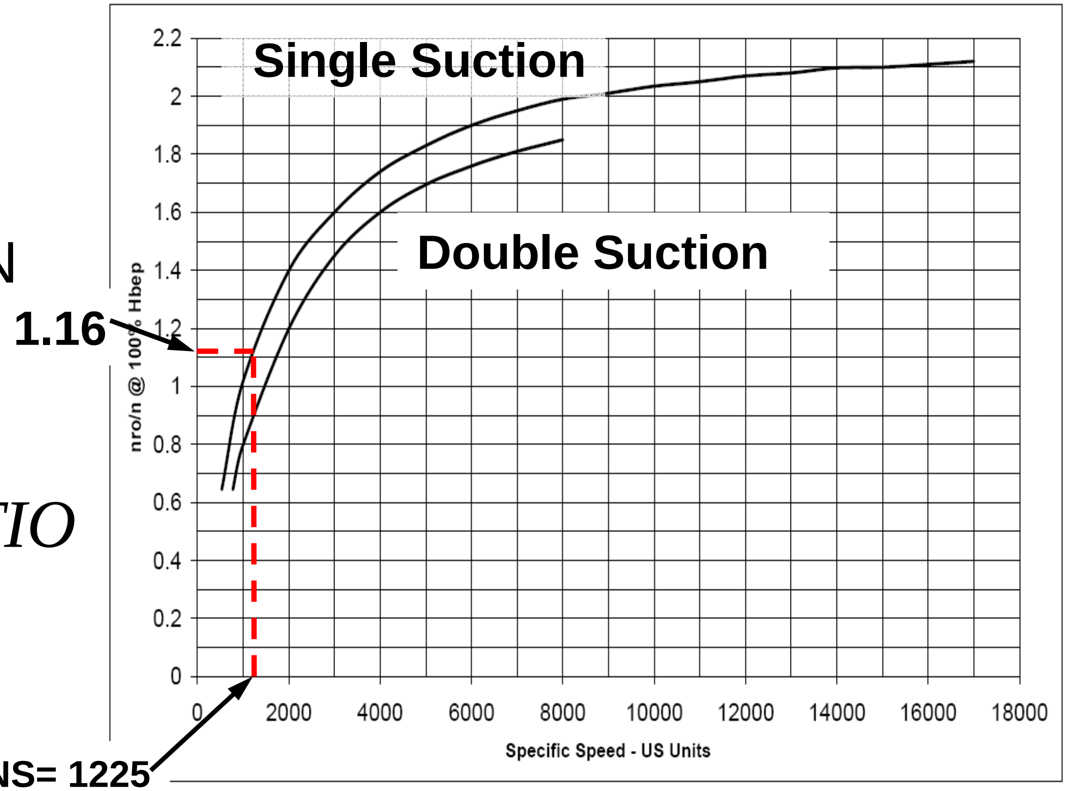


Characteristics of a similar hydraulic turbine.

With assumption of 100% flow, the question is what rotational speed will the pump achieve?

Speed From Hydraulic Institute 1.4

- QUICK
- SIMPLE
- GOOD APPROXIMATION



$$SPEED = DESIGN * RATIO$$

SPEED = 3577 * 1.16

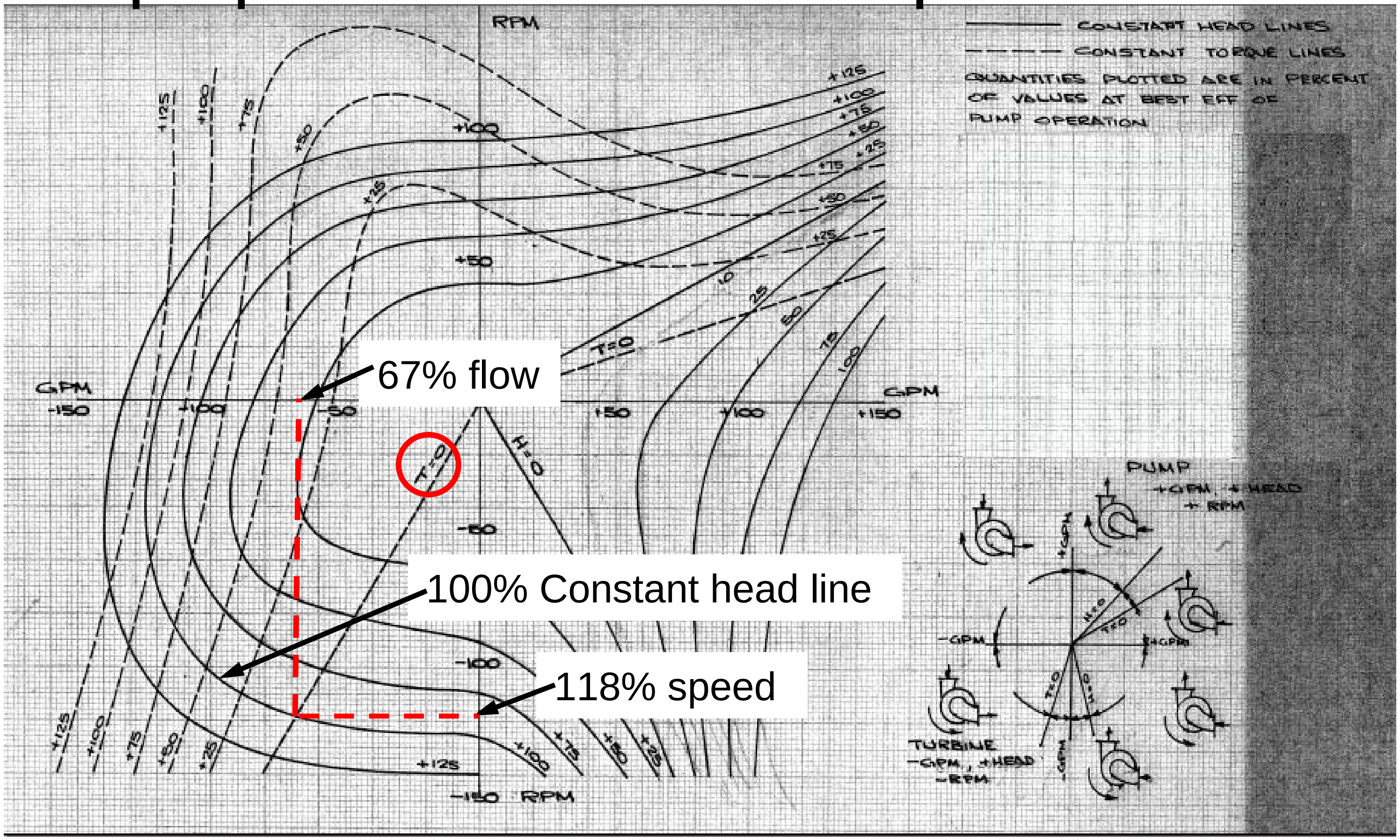
= 4142 RPM

Hydraulic Institute provides Quick speed check

NOTE: The higher the pump specific speed the higher the ratio ! Higher speeds are a result given the flow and head availability !

Speed From Four Quadrant Curve

Once the pump starts to rotate what final speed will be achieved.



Assume available pump back flow – head at 100%

Speed will increase until the head crosses the zero torque line.

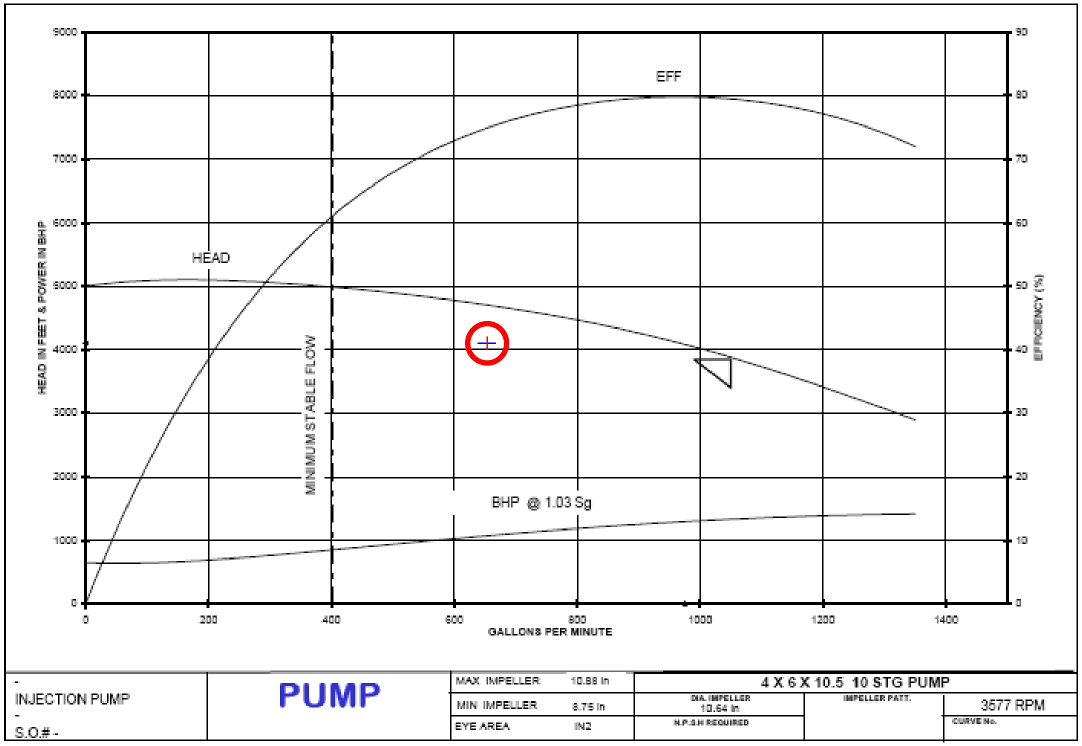
Follow to both horizontal and vertical axis

Speed From Four Quadrant Curve

HEAD = 100% = 4100 Ft

CAPACITY = 67% = 975GPM*0.67 = 653 GPM

SPEED = 118% = 3577*1.18 = 4221 RPM

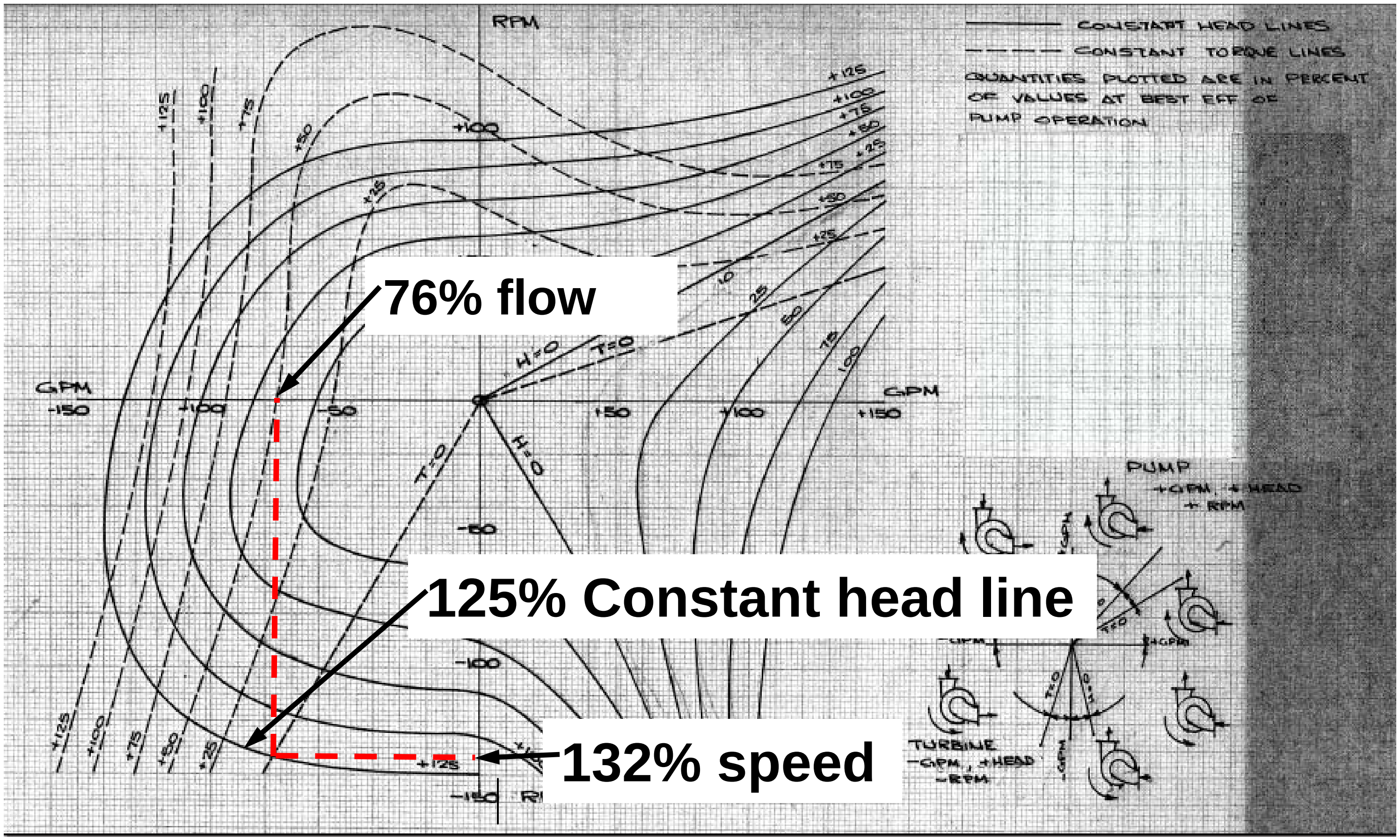


POINT IS BELOW THE CURVE!!

A second point is needed to determine the pull to the curve

Speed From Four Quadrant Curve

PICK A HIGHER HEAD – WE WILL USE 125% HEAD LINE



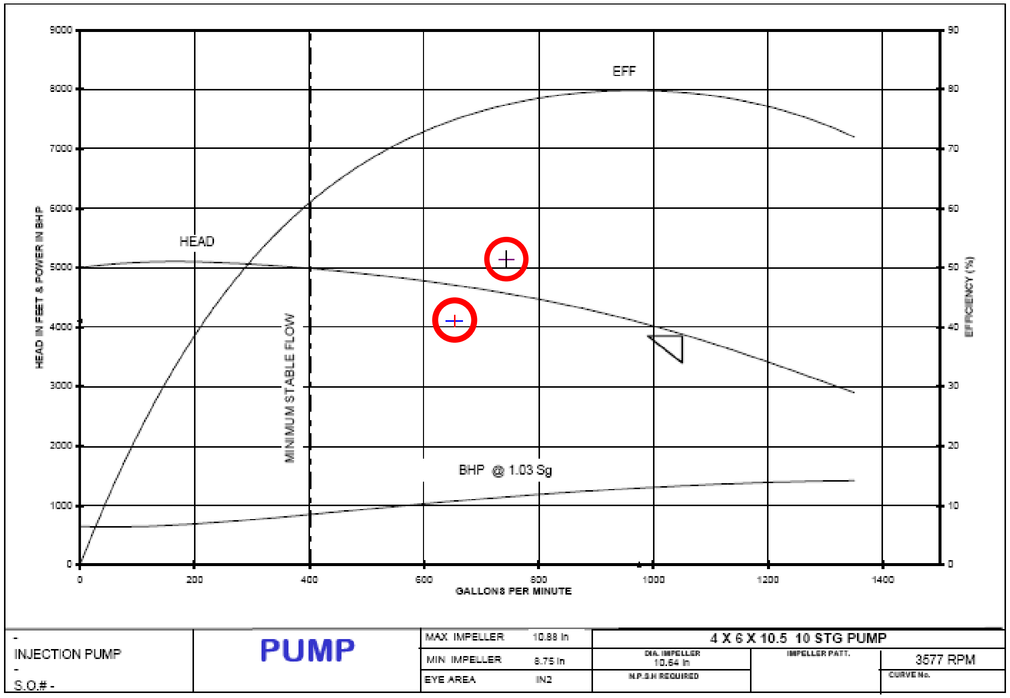
Assume available pump back flow – head at 125%
Again follow to both horizontal and vertical axis

Speed From Four Quadrant Curve

HEAD = 125% = 4100 Ft * 1.25 = 5125 FT

CAPACITY = 76% = 975 GPM*0.76 = 741 GPM

SPEED = 133% = 3577 * 1.33 = 4757 RPM



POINT IS ABOVE THE CURVE!!

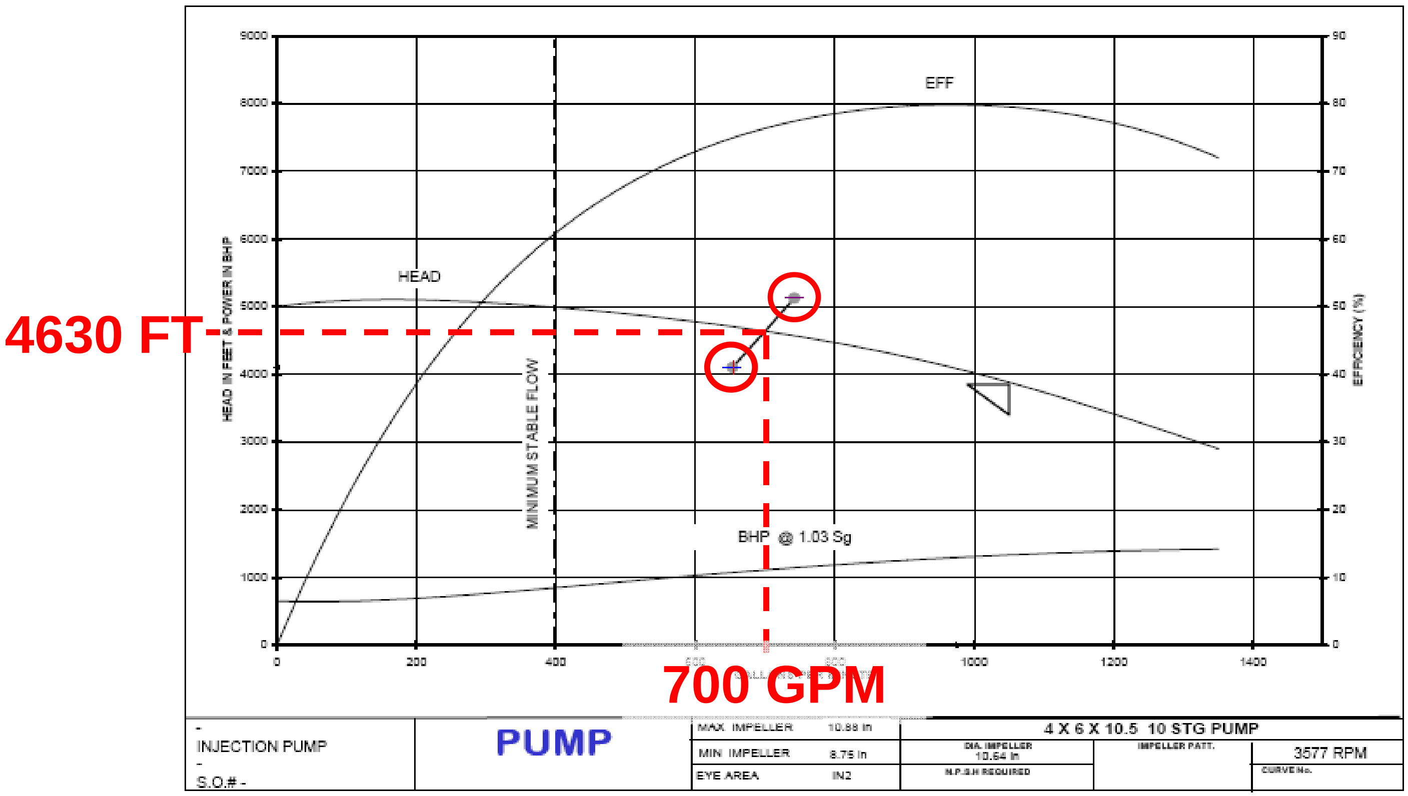
Speed condition is on the curve between our points

Speed From Four Quadrant Curve

Pull line crosses the curve at ;

HEAD = 4630 ft = 4630 / 4100 Ft = 113%

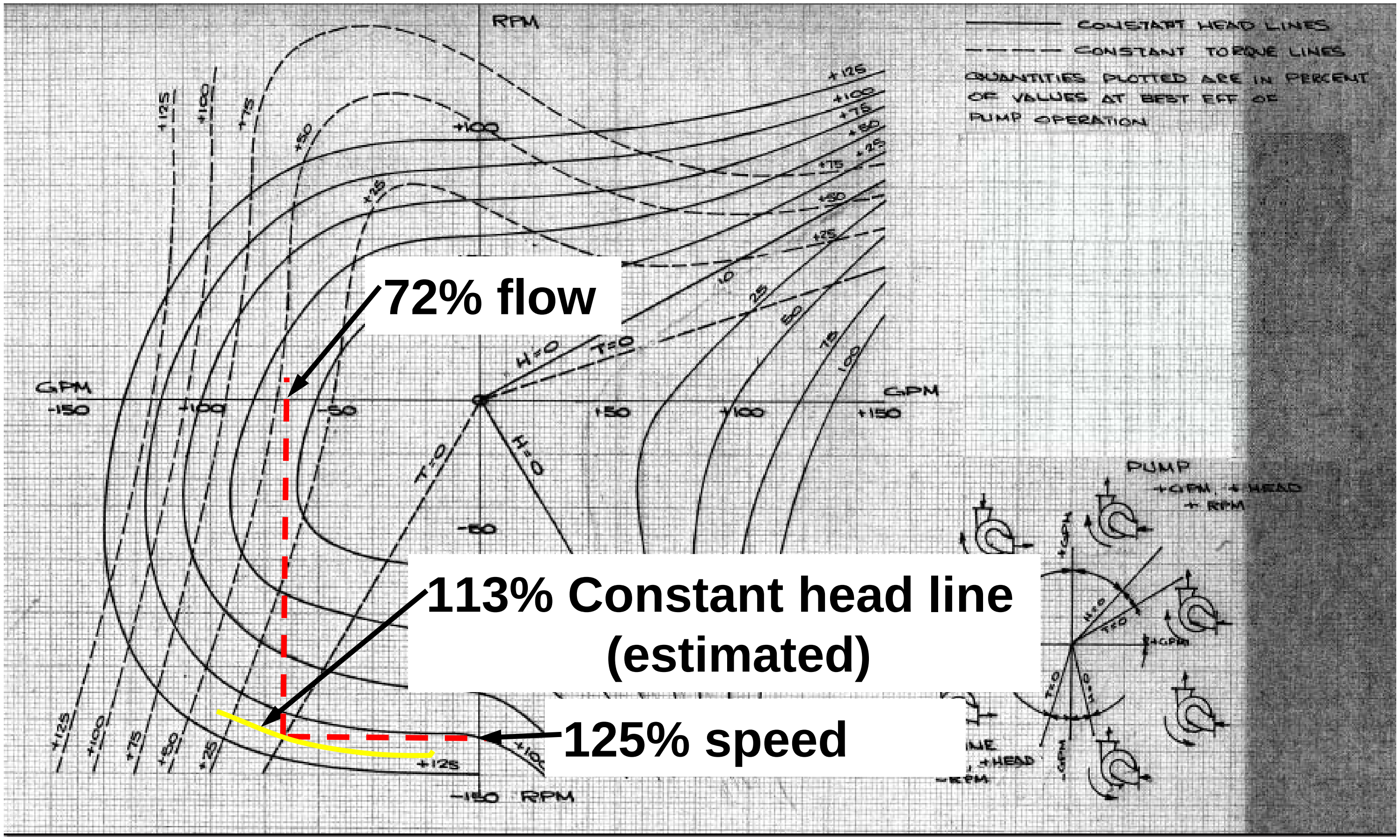
CAPACITY = 700 = 700 / 975 gpm = 72%



The final rotational speed can now be determined.

Speed From Four Quadrant Curve

Estimate head curve at 113%



From curve, estimate is 125% = 3577*1.25 = 4471 rpm

AFFINITY LAW CHECK

SUMMARY FROM QUADRANT CURVE

HEAD	**100% (4100 FT)**	**113% (4633 FT)**	**125% (5125 FT)**
CAPACITY	**67% (653 GPM)**	**72% (705 GPM)**	**76% (741 GPM)**
SPEED	**118% (4220 RPM)**	**125% (4471 RPM)**	**132% (4757 RPM)**

$$N = \left[\sqrt{\frac{CURVEHEAD\%}{QUADRANT\%}} * QUADRANTSPEED\% \right] * ORIGINALSPEED$$

N=[(113/100)^0.5*1.18]*3577 = 4486 RPM

N=[(113/125)^0.5*1.32]*3577 = 4489 RPM

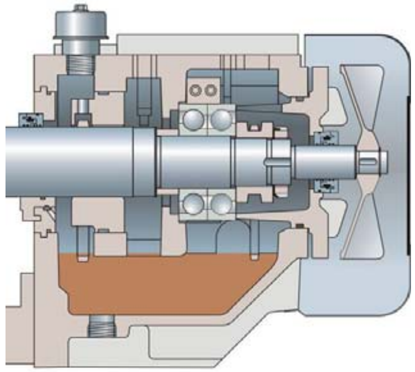
VALUE FROM QUADRANT CURVE = 4471 RPM

VALUE FROM HYDRAULIC INSTITUTE = 4142 RPM

What does this all mean?

- The pump and motor train will not reverse rotate under low flow conditions so no further consideration is required
- Pump will accelerate to 125% over speed with unrestricted head and flow rate.

PUMP CONSIDERATIONS



- Bearings
  - Oil rings operate in a limited speed range
  - Journal bearings
    - Lubrication at prolonged high speed will not be acceptable in most cases unless forced lube exists
  - Antifriction bearings
    - More tolerant of the lubrication starvation – see bearing manufacturer's catalog speed limitations.

More Considerations

Seals – This case has packingless boxes

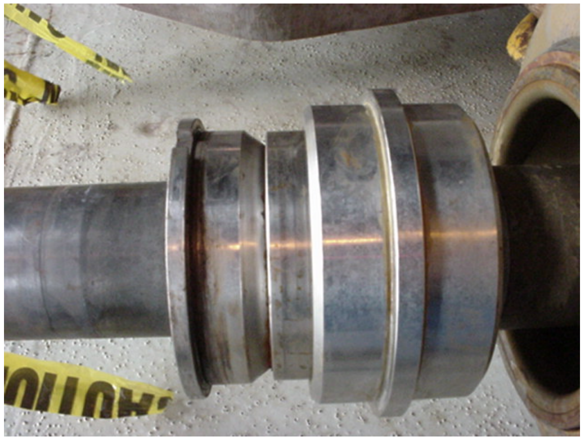
- Standard face seals may be adversely affected by overspeed.
- Pumping rings may be rotation sensitive

Pump internals

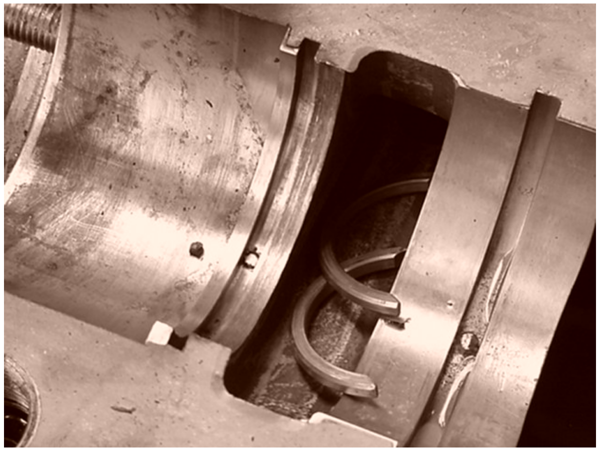
- Slow roll in either direction can damage wear parts
- Reverse flow creates internal differential pressures that were NOT considered in the pump design. Sleeves and wear parts can be displaced.

High runaway rotational speed

- Balance issues
- Impeller stresses can be exceeded



Throttle sleeve pushed off the fit and welded to throat



Throttle sleeve thrust rings

Support Equipment

High runaway rotational speed - cont'd

- Low damped critical speeds not normally of interest in rotor analysis may cause damage during runaway event

Coupling -

- Most modern disk type couplings will tolerate rotation in either direction
- Runaway pumps speeds can exceed coupling rating
- Possible energizing of reverse running equipment may over stress the coupling.

Motor –

- Bearing considerations similar to that of the pump
- Same high critical speed considerations as the pump
- Rotor overspeed can cause overstressing in the motor armature causing fits to loosen or parts to even be thrown.

Final thoughts

- **A discharge check valve stuck wide open will result in approximately 125% over speed with reverse rotation.**
- **Bearing failure is a definite possibility**
- **Seals were not rated for this rotational speed.**
- **Internal pump components may become dislodged**
- **High possibility of damaging vibration at over speed**
- **Coupling is rated for the rotational speed as long as the train does NOT become energized**
- **Motor has journal bearings. Over speed condition in either direction is of concern. Manufacturer should be consulted if a runaway event occurs.**

QUESTIONS