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An Experimental study on a Method of Computing Minimum flow rate

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1. Introduction

Many pump reliability problems in the Nuclear Power Plants (NPPs) are being attributed to the operation of the pump at flow rates well below its best efficiency point(BEP). Generally, the manufacturer and the user try to avert such problems by specifying a minimum flow, below which the pump should not be operated. Pump minimum flow usually involves two considerations. The first consideration is normally termed the “thermal minimum flow”, which is that flow required to prevent the fluid inside the pump from reaching saturation conditions. The other consideration is often referred to as “mechanical minimum flow”, which is that flow required to prevent mechanical damage.

However, the criteria for specifying such a minimum flow are not clearly understood by all parties concerned. Also various factor and information for computing minimum flow are not easily available as considering for the pump manufacturer’ proprietary.

The objective of this study is to obtain experimental data for computing minimum flow rate and to understand the pump performances due to low flow operation. A test loop consisted of the pump to be used in NPPs, water tank, flow rate measurements and piping system with flow control devices was established for this study.

2. Methods and Results

The tested pump is horizontal, a single stage canned motor pump, powered by 20 kilowatt (kW) (26.8 horsepower (HP)) electric motor. The design pressure is 150 psig and the design temperature is 180 °F. More detailed design data for the calculation of minimum flow rate are presented in Table 1.

Table 1: Design parameters of the tested pump

Design Parameters	value
Capacity(gpm)	35.0
Head(ft)	255
NPSHr(ft)	3.25
Speed(rpm)	3450
Design Power(hp)	12.5
Run-out Power(hp)	21.8
Shut-off Power(hp)	10.73

2.1 Thermal minimum flow

The Thermal minimum flow is normally associated with short term failure. As a centrifugal pump operates with reduced flows, the temperature rise of the fluid passing through the pump is increased due to the pump inefficiency. The pump hydraulic efficiency decreases as the pump flow reduces. The calculation of this flow value depends on pump horsepower, efficiency, developed head and pump suction conditions (NPSH, temperature, pressure).

The thermal minimum flow can be calculated according to Reference [1].

$$Q_{min} = 5.09 \times P / (\Delta T \times Cp \times s) \quad (1)$$

where P is pump input power at minimum (or shut-off)flow, hp
ΔT is maximum allowable temperature rise through pump, °F
Cp is specific heat, Btu/lb. °F
s is specific gravity

Generally, the limitation of temperature rise (ΔT)be recommended to a maximum of 15°F. From equation (1) and limitation of temperature rise, thermal minimum flow rate is :

$$Q_{min} = 5.09 \times 10.73 / (15 \times 1.0 \times 1.0) = 3.64 \text{ gpm}$$

2.2 Mechanical minimum flow

The mechanical minimum flow can be calculated according to Reference [2].

$$Q_{min} = Qr \times k1 \times k2 \times k3 \times k4 \times k5 \quad (2)$$

Where Qr is recirculation onset flow
k1 is power density factor
k2 is specific gravity
k3 is NPSH margin factor
k4 is pump intermittent operation factor
k5 is mechanical design factor, calculated by shaft stiffness

Using Equation (2) and data in Reference [2], the recirculation onset flow rate was given to 12.6 gpm.

$$Q_{min} = 12.6 \times 0.5 \times 1.0 \times 0.9 \times 1.9 \times 1.0 = 5.1 \text{ gpm}$$

2.3 Experiment of minimum flow

The test of thermal minimum flow was performed from 0 (shut-off) to 15.9 gpm and pressure and temperature were measured every 2 hours where inlet and outlet of the pump.

Figure 1 show the overall trend of the temperature rise versus flow. As the flow rate decrease, the temperature rise (ΔT) was increased to maximum 13.7°F at 2.19 gpm but was rapidly decrease at below this flow rate. The cause of re-decreasing temperature be guessed that the effect of temperature be not represented or the function that restricting temperature rise is installed below this flow rate (2.19 gpm).

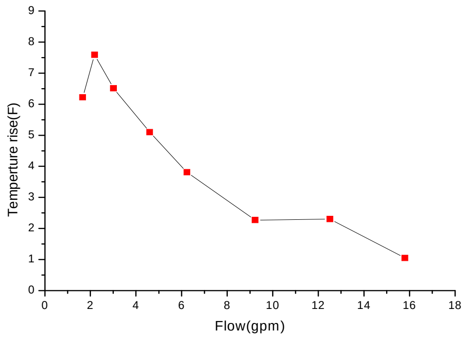

Fig. 1. Overall trend of temperature rise vs. flow rate.

The test of mechanical minimum flow was performed with throttling discharge flow at below BEP (5.3, 7.9, 15.9gpm respectively) and measured vibration data was analyzed with FFT method.

Figure 2 shows the spectrum of vibration was divided two region. At first region (0~1kHz) which is called "vane passing frequency region", amplitude dropped with decreasing flow rate. This means the hydraulic effect be decreased when vane passing flow was below. The other region(3~5kHz) which is called "cavitation region", overall amplitude was increased with decreasing flow. Also, at this region, irregular vibration was increased by the effect of cavitaion. The frequency span came to be narrow and amplitude increased at cavitation region when the flow reduced near to calculated mechanical minimum flow (5.1 gpm).

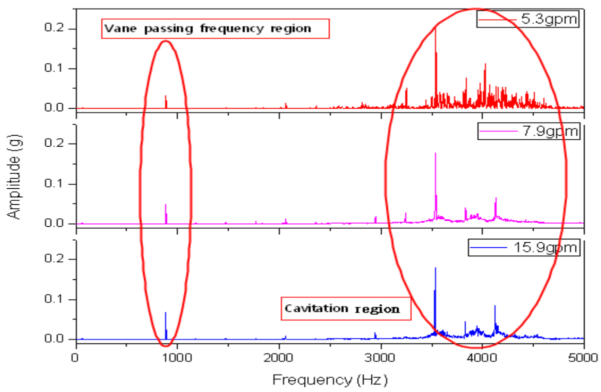

Fig. 2. Spectrum of vibration amplitude as reduced flow.

Figure 3 show the overall trend of the vibration amplitude at flow rate. As reduced flow rate, two point of inflection were generated in shown Fig.3. The first point at about 12 gpm, which is similar to calculated recirculation onset flow, can be explained that the recirculation was occurred at the inlet during operation at flow below BEP and the vibration happens by the recirculation. The second point is similar to calculated minimum flow which is 5.1 gpm and vibration amplitude rapidly was increased. The result of test be properly represented with computed value.

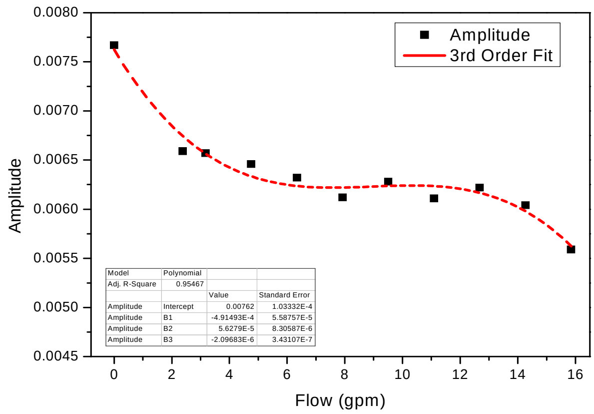

Fig. 3. Overall trend of the vibration amplitude (at 3~5 kHz) vs. flow rate.

3. Conclusions

The minimum flow test has been performed to verify the method of computing minimum flow and understand the affect of pump with decreased flow. The experimental results has a good agreement with calculated minimum flow rate which is recently recommended.

REFERENCES

[1] HI Centrifugal Pump Design and Application, 2000.
[2] S. Gopalakrishnan, "A New Method of Computing Minimum Flow", 5th International Pump User's Symposium, May 1988.