Product Data

Subject: PUMPING INDUSTRY TECHNICAL INFORMATION

Contents

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I. INTRODUCTION

A. Adjustable Speed Pumping

Pumping applications are found in a wide variety of industries, with an increasing trend to use adjustable speed control. These systems have grown steadily since the early 1950's, especially in process industries and freshwater and wastewater pumping.

The speed of a centrifugal pump is usually controlled for one of the following reasons:

To maintain pressure control as the flow changes (freshwater supplies, high rise buildings, industrial processes).

To maintain level control as the flow changes (sewage treatment plants, water treatment plants, industrial processes).

To maintain flow control as the system pressure changes (industrial processes).

To understand the language in the pumping industry and the application of adjustable speed controls, knowledge of hydraulic systems, pump characteristics and pump sensing systems is important.

II. HYDRAULIC SYSTEMS

Barometric pressure at sea level is 14.7 pounds per square inch (psi) and is called one atmosphere of pressure. A column of water 34 feet high at sea level will exert this same amount of pressure of 14.7 (psi) at the bottom of the column as measured by a gauge. This column of liquid is referred to as static head and is usually expressed in feet. Hence, pressure and head are different ways of expressing the same thing — pressure usually in pounds per square inch and head in feet.

$$\text{Head in feet} = \frac{2.32 \times \text{psi}}{\text{Specific gravity of liquid}}$$

Basically, the components for a centrifugal pumping system consist of a pump, a liquid and the pipe for transmission. The hydraulic system will include the following parameters, illustrated in Figure 1.

A. Static Conditions

Static Suction Head is the vertical distance in feet from the surface of the liquid at the intake source to the eye of the suction impeller.

Static Discharge Head is the vertical distance in feet between the eye of the suction impeller and the surface of the liquid at the discharge end.

Total Static Head is the sum of the static suction and static discharge heads — static implying that there is no movement of the liquid. Suction head is positive when the intake source is lower than the pump and negative when it is higher than the pump.

BASIC HYDRAULIC SYSTEM

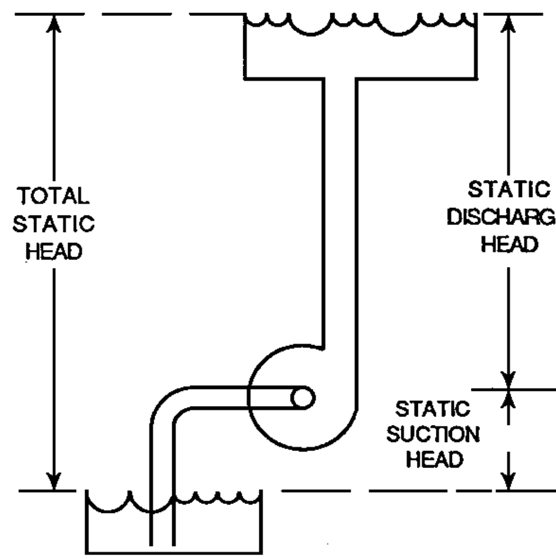

FIGURE 1

B. Dynamic Conditions

A hydraulic system presents a load to the pump and is usually illustrated as a *station curve*, illustrated in Figure 2.

When a pump is delivering a liquid in a hydraulic system, additional parameters become a factor.

Friction Head is the pumping head required in feet to overcome the friction of the liquid in the system due to the pipe, valves, fittings, etc.

$$hf = k\,f\,\frac{L\,V^2}{D}$$

hf = friction head
L = length of pipe
D = diameter of pipe
f = friction factor of pipe interior, elbows and valves
k = constant includes aging of the pumping system
V = velocity of the liquid

Velocity Head is velocity energy added to the liquid by the pump.

$$h_v = \frac{V^2}{2g}$$

Total Head, sometimes called Total Dynamic Head, is the sum of all the static and dynamic heads.

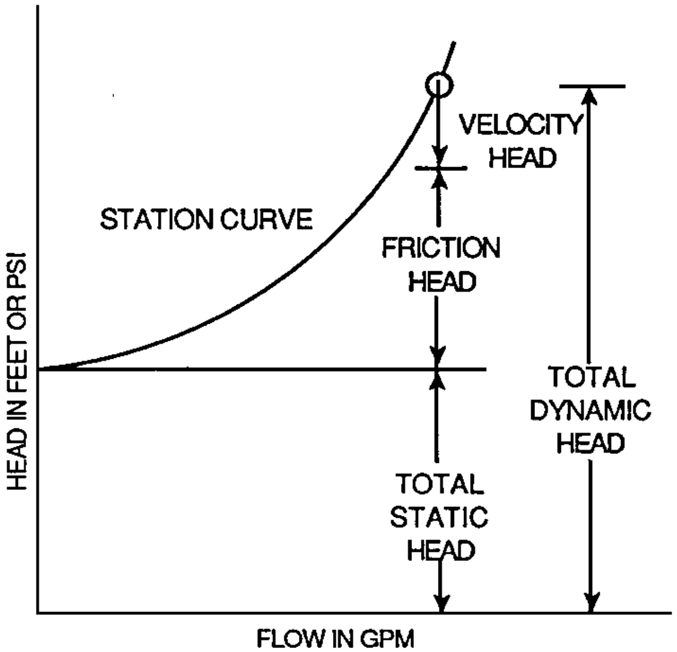

FIGURE 2

Some observations from the above relations are:

1. The higher the velocity of the liquid, the greater the head requirements of a pump.
2. The higher the lift of the liquid, the greater the head requirements of a pump.
3. The longer the pumping distance of the liquid, the greater the head requirements of a pump.

C. **Station Curves**

Station curves can take many forms, illustrated in Figure 3. A system having a long distance to pump but practically no vertical rise will consist of mostly friction head, as illustrated in curve 1. A system having a high short distance to pump with a large diameter pipe will consist of mostly static head, as illustrated in curve 2.

A station curve can be approximated by plotting two points on a graph having a head versus flow axis. The total static head of the system is plotted at zero flow. The other point is plotted at maximum flow and is the total dynamic head of the system. This total dynamic head is the sum of the total static head, the friction head and velocity head at maximum flow. The curve then varies between these two points as the square of the flow.

TYPICAL STATION CURVES

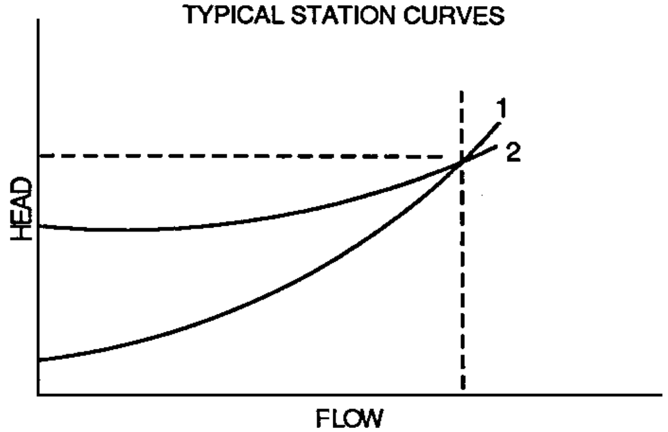

FIGURE 3

III. **PUMPS AND CHARACTERISTICS**

A. **Types of Pumps and Operations**

In the annual SIC census of manufacturers, pumps are grouped into four broad categories:

Industrial Pumps	Fluid Power Pumps
Domestic Water Pumps	Aerospace Fluid Power Pumps

Industrial pumps are the principal market for adjustable speed control. There are several design types of industrial pumps:

Progressing Cavity	Turbine
Reciprocating	Propeller
Rotary	Centrifugal

The progressive cavity type is similar to a large screw and is used to pump solids. It is used in the food industry and presents a constant torque load.

The reciprocating type presents a constant torque load and is occasionally driven at reduced speeds.

The rotary type, sometimes referred to as a "gear pump", is used for high pressure systems with low capacities and usually is not driven at reduced speeds.

Turbine pumps are high head pumps with large capacities and are frequently applied for adjustable speed installations — deep well, high rise buildings, etc.

The propeller type is similar in action to a ship's propeller, usually used for larger flows.

The centrifugal pump is the most common type and is frequently applied for adjustable speed in specific types of applications, such as wastewater treatment plants, freshwater systems and industrial processes.

In a centrifugal pump, the liquid enters a suction port in the center of the impeller. As the impeller rotates, the liquid is directed out over the vanes. This is illustrated in Figure 4. With an open discharge, the velocity of the liquid near the outside diameter of the impeller is greater than the velocity of the liquid just entering the suction port. This action causes an increase in pressure and is a function of the impeller diameter and impeller speed.

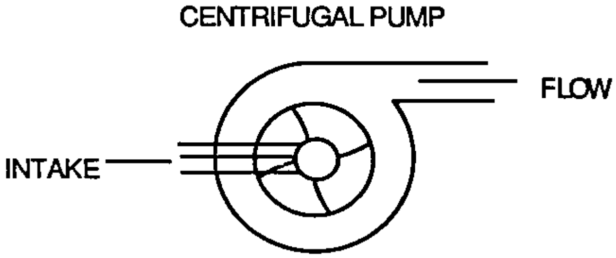

FIGURE 4

A centrifugal pump will theoretically develop its maximum head or pressure when flow is stopped by means of a valve in the discharge line. As the valve is opened and the liquid begins to flow, the head developed will decrease due to turbulence and friction in the pump.

B. **Affinity Laws**

In general, the performance of a centrifugal pump is governed by affinity laws which are listed below. These expressions are not always binding and should be used with discretion.

1. The capacity Q is directly proportional to the speed S with a fixed impeller diameter.

$$\frac{Q_1}{Q_2} = \frac{S_1}{S_2}$$

2. The head H developed is directly proportional to the square of the speed with a fixed impeller diameter.

$$\frac{H_1}{H_2} = \left(\frac{S_1}{S_2}\right)^2$$

3. The brake horsepower required at a pump shaft is directly proportional to the cube of the speed, with a fixed impeller diameter.

$$\frac{HP_1}{HP_2} = \left(\frac{S_1}{S_2}\right)^3$$

4. The capacity is directly proportional to the impeller diameter, at a fixed speed.

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$$

5. The head is directly proportional to the square of the impeller diameter, at a fixed speed.

$$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2$$

6. The brake horsepower required at a pump shaft is proportional to the cube of the impeller diameter, at a fixed speed.

$$\frac{HP_1}{HP_2} = \left(\frac{D_1}{D_2}\right)^3$$

C. **Centrifugal Pump Characteristics**

Pumps have head-flow characteristics, just like motors have speed-torque characteristics. At a fixed speed, the head developed by a pump will decrease as the flow is increased. Different designs in pumps will produce different characteristics, as illustrated in Figure 5.

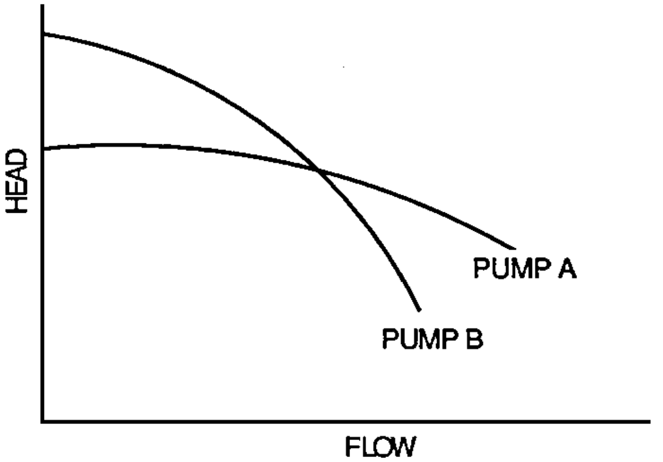

FIGURE 5

A set of characteristic curves for one type of pump is illustrated in Figure 6, for a pump with a fixed impeller diameter.

Note that there is a family of curves for the pump at various speeds. Use 1200 rpm as an example. With zero flow demand, the pump will develop about 75 feet of head (about 174 psi). As the flow is increased to 1000 gallons per minute, the head will drop to about 65 feet at an efficiency between 86 to 87%.

When a station curve is superimposed on the pump curves, speed and head requirements for the pump can be determined for flow conditions. As an example, consider the station curve in Figure 6. With this hydraulic system, 40 feet total static head is required at zero flow, and at 1600 gpm flow, the total dynamic head required is 140 feet. To deliver 1600 gpm, this pump will have to operate close to 1800 rpm.

CENTRIFUGAL PUMP CHARACTERISTICS AND STATION CURVE

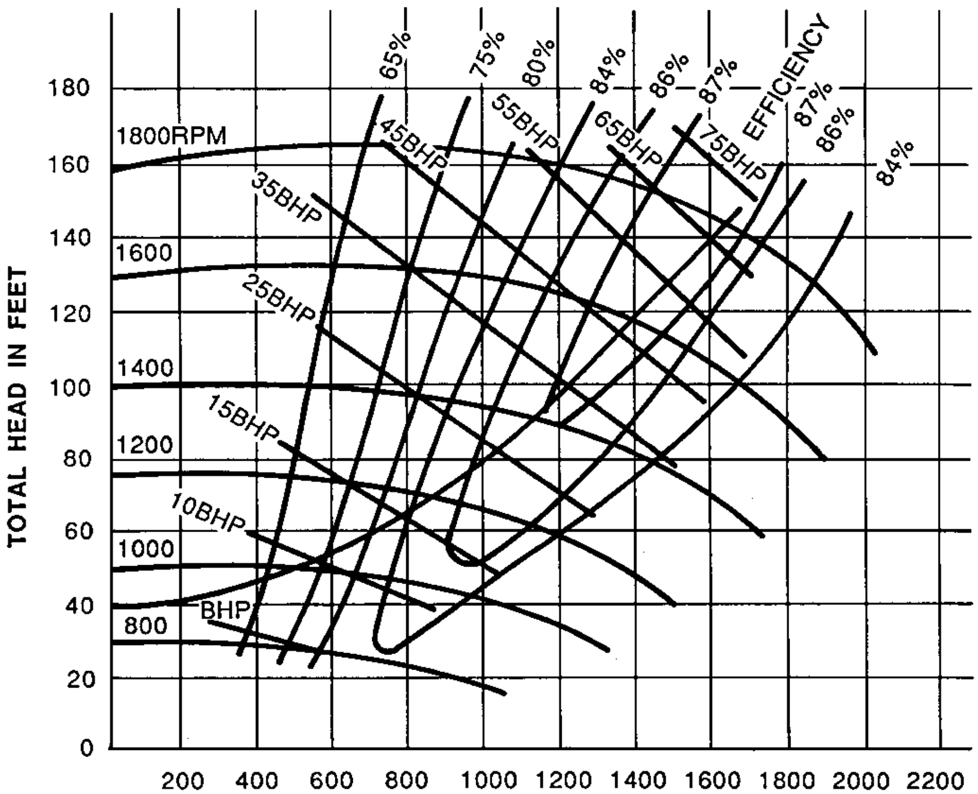

FIGURE 6

D. **Horsepower Calculations**

The horsepower required to drive a pump at any speed can be approximated without knowing the specific characteristics of the station curve or pump. If the total dynamic head (TDH), the maximum flow, and pump efficiency are known, the following formula can be used to calculate the horsepower load at full speed.

$$HP = \frac{(GPM)\ (H)\ (sg)}{(3960)\ (eff)} = \frac{(GPM)\ (psi)\ (sg)}{(1714)\ (eff)}$$

HP = Horsepower required to drive a pump.
GPM = Flow in gallons per minute from pump.
H = Total dynamic head in feet (includes total static head and friction head).
sg = Specific gravity (1 for water).
psi = Total dynamic head in pounds per square inch.
eff = Efficiency of pump. This can vary considerably depending on the design, manufacturer and the speed.

$$H = \frac{psi \times 2.31}{sg}$$

If complete hydraulic data is not known, the horsepower required to drive a pump at a reduced speed can be estimated by using the affinity law below. This rule is usually applied to define a theoretical pump load.

$$HP_{min} = HP_{max} \left(\frac{S_{min}}{S_{max}}\right)^3$$

This relationship, however, cannot be used in all cases since it is based on a condition where the specific gravity, total dynamic head, and efficiency all remain constant as the speed is reduced. In many applications, these parameters will change as the speed is reduced.

When engineering the pump director controller for an adjustable speed installation, the control manufacturer will usually request the pump curves and hydraulic data, to ensure that the control is being applied properly.

IV. SYSTEM SET POINT CONTROL

In pumping, various control systems are used to control the sequencing and speed of pumps in a system. Two broad categories are system set point control and pump sequencing control. System set point control will determine the hydraulic system operation, and pump sequencing control will determine the pump performance. There are two types of set point control:

Proportional Control
Proportional plus Integral Control

A. Proportional Control

Proportional control will permit a pumping system to change proportionally within specified limits and with specific functions occurring to maintain those limits.

An example of proportional control is a pumping system with a wet well, illustrated in Figure 7. Liquid flows into the well at various rates. The objective is to pump the liquid out with gradual changes in the flow.

Lead & Lag pumps pump liquid out at variable flow rates to maintain the liquid within certain levels in the well as the inflow changes. At full speed, both pumps have ample capacity to keep the wet well from overflowing. Controlling the functions between levels (1) and (6) is proportional control. The speed of the pumps will be controlled to change proportionally with the level, as it rises or falls within the specified levels.

Many wet well installations use proportional programming control — but in some cases proportional plus integral control is used also. Figure 7 is only one example. There are many different variations of level-sensing proportional control.

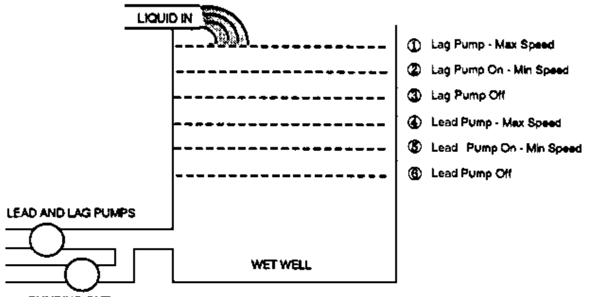

FIGURE 7

B. Proportional Plus Integral Control

Proportional plus integral control will permit a pumping system to maintain a relatively constant hydraulic system operation, with specific functions occurring to maintain a constant set point.

An example of proportional plus integral control is a water pumping system illustrated in Figure 9. Water demand in the system keeps changing as various valves are opened and closed. The objective is to maintain constant pressure in the system as the flow changes. (Note from Figure 5 that the pump head drops as the flow increases at a fixed speed. Increasing the speed with the same flow rate will increase the head or pressure to keep it constant.) A surge or cushion tank is required in these systems to dampen pressure transients in the system.

In this example, as the flow is increased, the pressure will start dropping from its constant point (15 psi). The speed control signal will change to whatever value is necessary to bring the pressure back to 15 psi. The faster and greater the pressure change, the larger the value of signal generated in the control to correct the speed.

A pressure transducer is used to sense the pressure in the system and provide the feedback for the integral control system.

Controlling the speed between relatively small ranges to maintain a constant set point is called proportional plus integral control and can be used to maintain constant pressure, constant flow or constant level in a pumping system.

C. Level Sensing Systems

There are various types of level sensing systems used to provide the speed signal for set point control:

Capacitive
Pressure
Float
Sonic
Bubbler

Capacitive sensing systems use a series of probes immersed in the liquid. As the level changes, the capacitance will change. This can be converted into a voltage or current signal for speed control.

Pressure sensing systems use a sealed device with a diaphram immersed near the bottom of the liquid. As the level changes, the pressure will change in the sealed system. This is converted into a voltage or current signal for speed control.

Float sensing systems use a float on the surface which operates a potentiometer through a connecting means. As the level changes, the float will move to change the position of the potentiometer. This is converted into a voltage or current signal for speed control.

Sonic sensing systems employ a high frequency sound emitted from an electronic device mounted above the liquid. As the level changes, the sound wave beamed to the surface of the liquid will reflect a change in the electronic circuits. This is converted into a voltage or current signal for speed control.

Bubbler sensing systems use a small tube extending to near the bottom of the liquid, illustrated in Figure 8. A small compressor is used to force air through the bubbler tube. A constant differential relay (air flow regulator) maintains a constant flow of air through the bubbler tube, regardless of changes in pressure from the level rising or falling. In other words, the pressure in the bubbler tube is changed as the level changes, to maintain a constant volume of air flowing out the bottom. A pressure transducer responds to the pressure in the bubbler which is directly related to the liquid level. This is converted to a voltage or current signal for speed control.

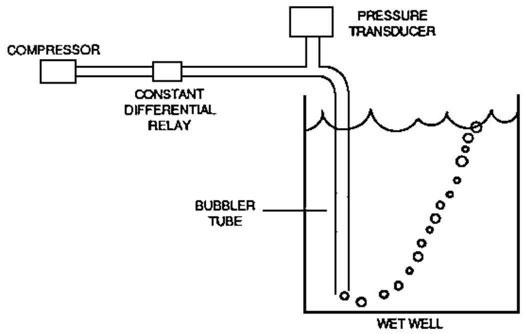

FIGURE 8

Of all the various types of level sensing systems, the bubbler is the most frequently specified by consulting engineers. Considering all the various conditions and requirements for level sensing installations, overall, the bubbler has been the most successful for over 20 years.

V. PUMP SEQUENCING CONTROL

There are two types of pump sequencing control.

Pump staging control
Pump load share control

A. Pump Staging Control

Pump staging control will permit 2 or more pumps to operate individually in sequence to satisfy the hydraulic system demand. For example, a lead pump may operate over a speed range to deliver minimum to maximum flow. If the flow demand continues to increase, the lead pump will remain at full speed, and the lag pump will operate over a speed range to deliver its minimum to maximum flow. The pumps will operate in a similar manner on decreasing demand.

B. Pump Load Share Control

Pump load share control will permit two or more pumps to operate together to share the load to satisfy the hydraulic system demand. For example, a lead pump may operate over a speed range to deliver minimum to maximum flow. If the flow demand continues to increase, both the lead and lag pumps will be adjusted to the same speed, to meet the flow demand, thereby sharing the load. On decreasing demand, below maximum output of the lead pump, the lag pump will shut down, and the lead pump will operate over the speed range.

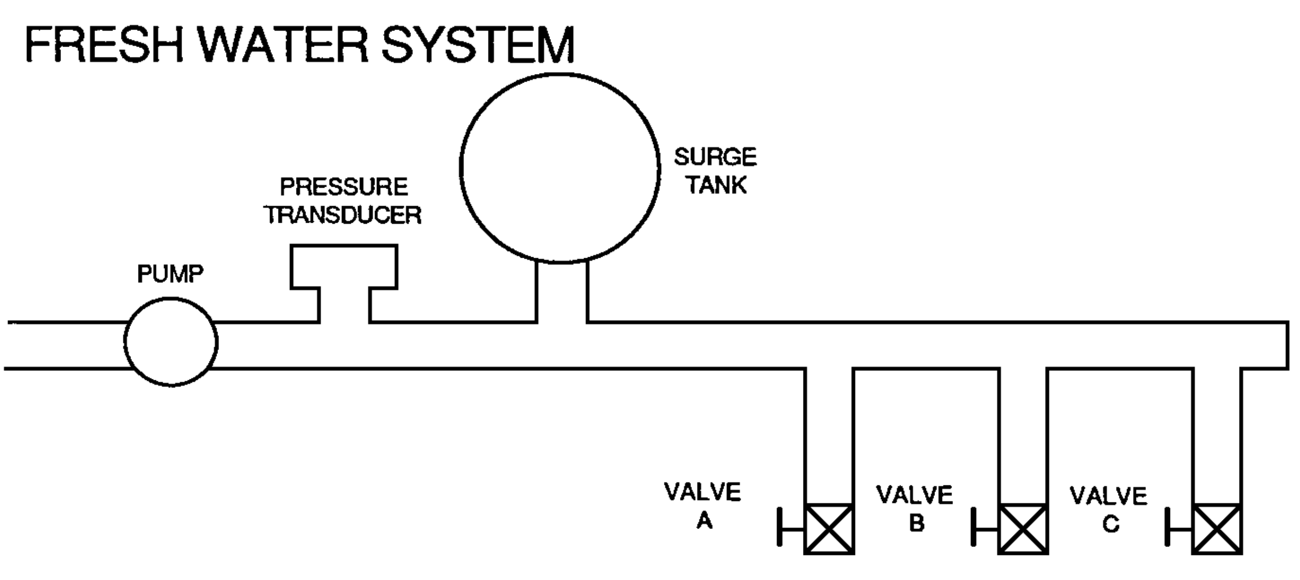

FIGURE 9

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