Water hammering in fire fighting installation

Forward

One of major problems raised in the fire fighting network installed at Pioneer company for pharmaceutical industry /Sulaymania was the high water hammering during the testing and operation of the system

This work goal is to find out the reason(s) of the phenomena

The designer had take the standard criteria to insure proper operation of the system

This work is based on analyzing the hydraulic characteristic of the pumping station with the net work

The transient analysis was done to predict the level of hammering in order to study the dynamics of the system

Software called (AFT Impulse) was used for analysis

١-*Basic theory of water hammer*

Water hammer is a phenomena associated to most pumping stations

It occurs when a valve is suddenly turned off, or a trip of the pump occurs, the velocity change of moving fluid will change to pressure waves.

The wave travels along the piping in speed of sound, causing high impacts on piping elements and supports.

Joukowsky equation is

$$\frac{\partial P}{\partial t} = \rho a \partial v / \partial t$$

$$\Delta P = \rho a \Delta V \text{ --------------(١)}$$

Where

P = pressure

V = velocity

A sound speed in the fluid

? fluid density

t time

Equation for wave speed

As the speed of sound in a fluid is the

$$\sqrt{effective\ bulk\ modulus/density}$$

, the peak pressure will depend on the fluid compressibility if the valve is closed abruptly or a pump is tripped

$$a = \sqrt{\frac{k}{\rho}/[(١ + \frac{V}{a})\{١ + \left(\frac{K}{E}\right)\left(\frac{D}{T}\right)c\}]}$$ ------------------(٢)

,

where

a = wave speed

K = bulk modulus of elasticity of the fluid

ρ= density of the fluid

E = elastic modulus of the pipe

D = internal pipe diameter

T = pipe wall thickness

c = dimensionless parameter due to system pipe-constraint condition on wave speed

Expression for the excess pressure due to water hammer

When a valve with a volumetric flow rate Q is closed, an excess pressure δP is created upstream of the valve, whose value is given by the Joukowsky equation:

$$\partial P = Z_h Q \text{---------------------------} ٣$$

In this expression

Over pressurization δP is expressed in Pa;

Q is the volumetric flow in m٣/s;

- Z_h is the hydraulic impedance, expressed in kg/m٤/s.

The hydraulic impedance Z_h of the pipeline determines the magnitude of the water hammer pulse. It is itself defined by:

$$Z_h = \sqrt{\rho B_{ef}} / A \text{-----------------------------} ٤$$

with:

ρ the density of the liquid, expressed in kg/m^{٣};

A cross sectional area of the pipe, m^{٢};

B_{eff} effective modulus of compressibility of the liquid in the pipe, expressed in Pa.

The latter follows from a series of hydraulic concepts:

Compressibility of the liquid, defined by its adiabatic compressibility modulus B_l, resulting from the equation of state of the liquid generally available from thermodynamic tables;

the elasticity of the walls of the pipe, which defines a modulus of equivalent compressibility B_{eq}. In the case of a pipe of circular cross section whose thickness e is small compared to the diameter D, the equivalent modulus of compressibility is given by the following formula:

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- $B_p = eE/D$; in which E is the Young's modulus (in Pa) of the material of the pipe;
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- possibly compressibility B_g of gas dissolved in the liquid, defined by:
- $B_g = P/\alpha$
  - γ being the ratio of specific heats of the gas
  - α the rate of ventilation (the volume fraction of undisclosed gas)
  - and P the pressure (in Pa).

Thus, the effective compressibility modulus is:

$$١/B_{eff}= ١/B_l +١/ B_p +١/B_g \quad \text{-----------------------------(٥)}$$

As a result, we see that we can reduce the water hammer by:

- increasing the pipe diameter at constant flow, which reduces the inertia of the liquid column;
- choosing to use a material with a reduced Young's modulus;
- introducing a device that increases the flexibility of the entire hydraulic system, such as a hydraulic accumulator;
- Where possible, increasing the percentage of undisclosed air in the liquid.

The water hammer effect can be simulated by solving the following partial differential equations.

$$\frac{\partial V}{\partial X} + \frac{١}{B_m} * \frac{\partial P}{\partial t} = ٠$$

$$\frac{\partial V}{\partial t} + \frac{١}{a} * \frac{\partial P}{\partial x} + \frac{f}{٢D} * V\lfloor V \rfloor = ٠ \text{-------------------------(٦)}$$

Where *V* is the fluid velocity inside pipe, ρ is the fluid density and B_m is the equivalent bulk modulus, *f* is the friction factor.

System description

The existing fire fighting system consist of mane lope of birdied ductile iron, ٨ inches in diameter, and branches

Two branches for each building, the branches are feeding fire cabinets which are distributed in the building

Above ground distribution network are constructed of ٤ inch galvanized steel

The highest fire cabinet is located at ٢٠ m above the finish floor

The fire fighting net work is supplied by two main pumps, one off is electrically driven by ٤٥ kW motor, the other is diesel generator

Driven, for emergency

An n underground concert tank ٤٠٠ m٣ capacity is the main supply of the system

Fig -١ is a layout of the landscape of the network.

System specifications

The existing system consist of the following parts

١- ٤٠٠ m٣ fire tank , constructed off reinforced concrete

٢- Pumping station , consisting of

  A- A-C electrical motor driven , horizontally split case fire pump

  ITT-SERIES ٨١٠٠ size ٨x٦x١٨F , ٧٥٠ GPM @ ٨٠ PSI

  B- Diesl generator driven with the same as above

  C- Jokey pump , vertical multistage model ITT-٣٣ SVBC٠٦١٨ Flow ٥ l/s @ ٧٠ m head

d- hydro-pneumatic tank model FX ٣٠٠ ,size ٣٠٠ l

٣- Landscape network forming a closed loop around the protected area , consisting of buried ٨ inch ductile iron piping
There were ٥ hydrants, with ٢١/٢ inch size landing valves, and ٢٠٠ GPM flow capacity
٤- Inside building
The both production buildings are protected by this system
Each building are supplied with two riser of ٤ inch size galvanized steel pipe
The distribution piping forms a closed loop at each elevation, the loop size is ٤ inch, the fire cabinets are feed via ٣ inch galvanized steel branch
٥- Fire hydrants , consisting of ١ ½ inch landing valve with ٣٠ meter hoses , flow of each hydrant is ١٠٠ GPM
System modeling
We will use the pipe ٢٠٠٠ soft ware to analyze the entire system both steady state operation and transient period to predict the behaviour of system dynamics
The only event which will close water hammering in the systems like fire fighting networks is the pump trip, other cases like sudden valve closure is not happen hear
To reduces the size of working file and to reduce run time of the program, and to focus on the branches at fire hydrants and the We did the following
١- fire hydrants are substituted by hydraulic resistant at the risers
٢- the hydrant most remote of the pumping station was consider to be in operation , others are closed
٣- the hydraulic resistant are calculated according to the real piping and fitting configurations

٤- using deferent flow rates to predict effect of flow variation on the dynamics of the piping

٥- using two deferent water hammer arrestors , bladder tank and relief valve

The fig no – is the model which will be analyzed

Calculations

١- flow coefficients

This concept is used to define characteristics of valves and nozzles it's described by Cv

Q= Cv $\sqrt{\Delta P/Sg}$

Q flow rate $F^{٣}$/S

ΔP= pressure drope psi

Sg = specific gravity of liquid

٢- flow resistance

This concept is used to define characteristics of pipes and fittings denoted by R

R= Hl/ $Q^{٢}$

Hl= head loss in FOOT

Q flow rate $F^{٣}$/S

According to above definition, the resistance of valves and fittings will be as follows, Sg =١ for water

$Q^{٢}$=$Cv^{٢}$XΔP
$\Delta p/Q^{٢}$= ١/$Cv^{٢}$
To convert in foot of water multiply by ٢.٣
Hl/$Q^{٢}$= ٢.٣/$Cv^{٢}$

Combined resistance of two components in series is

R= R١XR٢/$\sqrt{(R١^{٢}+R٢^{٢})}$

Calculating the branch of most remote hydrant (see fig. no. ---)

The total resistance will be

١٠٣٤٠ S/ $m^{٥}$

٣- wave speed
Bulk modulus of water ٢٢E٩ Pa (N/M٢)

Recalling equation ( )
Bulk modulus of pipe Bp = $^{eE}/_{D}$

e = pipe thickness = ٠.٣٣٥ inch (٠.٠٠٨٥ m)
E modulus of electricity of the pipe material
B_{ef}= ٥.٩E٩ pa

Hydraulic impedance
Z_h= $\sqrt{١٠٠٠X٥.٨E٩}$/٠.٠٣٥٣
= ٦٨٢٢٤٣٣١.٢ KG/M٢.S
Pressure rise due to sudden valve shutdown
ΔP= ٠.٠٤٧X ٦٨٢٢٤٣٣١.٢

= ٣٢٠٦٥٤٣.٥ pa= ٣٢bar

If a gas chamber added to the system with pressure equal to system pressure

The effective bulk modulus will be

B_{eff}= ٦٩٩٩١٦.٢

$$Zh = ٥٦٢٨٩٢\ Pa = ٠.٥\ kg/cm^{٢}$$

Analyzing the whole system by a computer software

The software used is

Key pipe ٢٠٠٠

It's a demo version, so it's limited in to use in the following

١- pipe material – concert and ductile iron can be used
٢- pipe size , upper limit is ٨ inch
٣- no excess to change default fluid properties
   Fortunately the fluid is water
٤- total pipe length shall not exceed ١٠٠٠ m

Analysis Cassese

The Maine cause of the hammering in the system under consideration is the pump trip,

The pump is controlled by a pressure switch, as the pressure reaches the predefined value the pump will trip

The following cases are analyzed

A- system without expansion tank
B- system with deferent sizes of expansion tanks
C- Effect of tank piping on the performance of the system

Results

A- surge tank size
 the total volume of the system is ٤٥ $m^{٣}$, an approximate tank size based on water bulk modulus of ٢٢E٩ Pa is ٢٠٠ l tank
 the analysis shows that this volume is not correct size
 the reason is the dynamic effect of the system.
 Sea fig( )
B- effect of tank preset pressure
 low preset pressure will reduce the gas volume at operation , so reduces the system flexibility , high pressure dose the same
 the tank pressure must be kept near the minimum system pressure
 sea fig.
C- effect of piping connecting the surge tank with the system
 size of pipe connecting the surge tank to the system has major effect on the performance of the tank
 hydraulic resistant must be kept minimum for water inlet to the tank , but some throttling is necessary for outlet

Deferent analysis results are represented as graphs', showing the variation of pressure at main header and surge tank with time

Conclusions

١- the system was well designed
٢- the surge tank preset pressure must be adjusted to ١.٨ bar

٣- the connection of the surge tank shall be changed to ١-١/٢ inch pipe
٤- hydrant net works shall be equipped with automatic venting valves
٥- Periodic check of the surge tank pressure required.

References

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School of civil and environmental engineering, Georgia institute of technology