Effect of Pump Inertia & Valve Closure time on the Transient Flow Condition of a Water Supply Network: A Case Study

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Abstract— *Water distribution network is the most essential part of world's infrastructure. The main purpose of water supply system is to supply the required amount of water at the desired head to all the consumers. Any water distribution scheme comprises of water intake, treatment plant, pumping mains and distribution lines. In the present work pumping mains are designed to supply water to 30 OHT (Over Head Tank) which fulfills the demand of 74 villages and 2 towns located in Budni Block of Sehore district in Madhya Pradesh(India). The clear water pumping lines are designed to fulfill the demand up of 20 years taking 2015 as base year. The steady flow analysis is done by using Bentley software. The designed pipes are required to be checked for their safe working during minimum and maximum pressure development in these pipes because of sudden closure of valves and shutdown due to pump failure. All these circumstances creates the transient flow condition. In present work Transient flow analysis of the designed pumping network is carried out to see the maximum and minimum pressure generated due to sudden valve closure and shutdown of supply pump. The effect of control valve closure time and pump inertia on maximum and minimum pressure in the pipes is analyzed by varying valve closing time and pump inertia to 6-8 different values. It was found that maximum and minimum pressure at different pipe located in pumping network are greatly affected by inertia of the pump and control valve closing time.*

Keywords— *Hydraulic transients, pump inertia, valve closure time, water hammer*

I. INTRODUCTION

In large water distribution networks the supply is mostly done by using pumps of suitable sizes. The size of the pump mainly depends on the quantity of water required to be supplied and the pumping hours of supply. A water distribution system consists of many components, and when there is sudden closure of valve due to power shutoff or pump failure it causes sudden change in flow conditions The change shifts through the system as a pressure wave and causes water hammer conditions. Avoiding the effects of water hammer is of major concerned in pipe technology. Hydraulic transient is a flow condition where the flow velocity and pressure change rapidly (very fast) with time in pipelines filled with water. Hydraulic transient can collapse a water distribution system, and as such it is essential to analyse it in order to determine the values of maximum and minimum transient pressures that can result from flow control operations . It is required to establish the design criteria for system equipment and devices so as to provide an acceptable level of protection against system failure due to pipe collapse or bursting[3].

The transient flow condition in large pipe may be due to sudden closure of the control valve or failure of pump or planned pump stop. Thus the inertia of pump and the valve closure time significantly effects the maximum and minimum pressure due to surge in the pipe line.

Many researchers contributed in the study of transient flow conditions, due to valve closure and inertia of the pump. Mosab[9] studied the effect of pump inertia and valve closure time and found that the stepwise valve closure can reduce transients significantly than the linear valve closure operation. A pump with a high inertia can also reduce transients significantly. It is found that network junctions, bifurcations flow passages are affected by the passage of the reflection and refraction of waves in the water hammer. Rao[11] used the simulation software to study the Increased pressure in the pipes and presented in the manual calculation of the parameters . The results are compared with the available experimental data.

In the present work the transient flow analysis of the clear water feeder network of Baneta water distribution system which is a part of Baneta water supply scheme Dist Sehore is done by using Bantley water hammer software. The effect of pump inertia and valve closure time on transient flow performance of the Clear water feeder network is studied. It is found that the control valve closure time and inertia of the pump significantly effects the maximum and minimum pressure at different pipe locations of the pumping network.

Study Area

The study area is located in Budni Block of Sehore district of Madhya Pradesh. Presently there is no water distribution system in these villages and the only source of obtaining water is through hand pumps, which is inadequate for the increasing population of the villages. The scheme proposes to supply water to 74 villages and 2 towns having 30 OHT (Over Head Tank). The water distribution scheme comprises of (a) distribution network to supply water to villagers from 30 overhead tanks located at different locations of the villages. (b) The clear water pumping mains to fill up the over head tanks by using centrifugal pumps and (c) The raw water pumping system which takes raw water from Narmada river and supplies it to water treatment plant. The pumps of clear water pumping mains are designed to supply water for next 20 years. The design details of the pumping network which is divided in teo phases are shown in figure 1 and 2. The supply to the feeder network is done by centrifugal pumps.

II. THEORY

Water hammer analysis of the feeder networks are done by Bantley Water Hammer software[3]. This software calculates the maximum and minimum pressure in pipe network by using method of characteristics. The software is having in built capacity of changing the pump inertia and valve closure time as per the requirement.

Pump inertia

The pump inertia or moment of inertia of a pump is its resistance to change in angular velocity as it rotates about its shaft. Knowledge of the moment of inertia of a pump, motor and associated components is typically required for transient analysis of a pumping system. It is the resistance of the pump to acceleration or deceleration. Pump inertia is constant for a particular pump and motor combination. The higher the inertia of a pump, the longer it takes for the pump to stop spinning following its shutoff and vice versa [5]. Pump inertia can be increased by use of a flywheel. The high value of pump inertia can control the high surge in pipe line but mechanical problems associated with high inertia pumps make it impractical. Total inertia of the pump includes inertia of pump and motor both. Pump inertia is calculates as

$$I_{Pump} = 1.5 * 10^7 * \left(\frac{P}{N^3}\right)^{0.9556}$$

Where, I_{Pump} = Pump Inertia in kgm^2

P = Power in kW

N = Rotational Speed of the pump in rpm

Motor Inertia is calculated as

$$I_{Motor} = 118 * \left(\frac{P}{N}\right)^{1.48}$$

Valve closure time

The time taken for the linear closing of control valve affects the maximum and minimum pressure occurred in the different pipes of the feeder network.

III. PROBLEM STATEMENT AND ANALYSIS

The water source for Baneta water supply scheme is river Narmada near Block Budni, District Sehore. The water from Water treatment Plant (WTP) located at Baneta is supplied to the overhead tanks (OHT) located in all 15 zones and 2 towns of Budani block. The total pumping network for feeding clear water is divided in 2 parts. The pumping network-1 feeds to 5 existing and 3 proposed OHTs and 1 groundwater tank at Budni. The pumping network feeds to 11 existing and 11 proposed OHTs. Clear water main distribution line is designed by using coated ductile iron (DI) K-9 pipe to supply water from water treatment plant to 30 OHTs and 1 ground water tank at Budni. The pumps of capacity 109 kW and 107 kW are proposed for each network for 16 hours running of the pumps.. The details of the network are shown in fig.1 and 2. Water hammer analysis of the feeder network is done by Bantley Water Hammer software. This software calculates the maximum and minimum pressure in pipe network by using method of characteristics. The software is having in built capacity of changing the pump inertia and valve closure time as per the requirement.

The complete network is designed by DI K-9 pipe of sizes 100 mm, 125 mm,150mm, 200mm, 250 mm,300mm and 350 mm. The total length of pipes used for the network is 104 km.

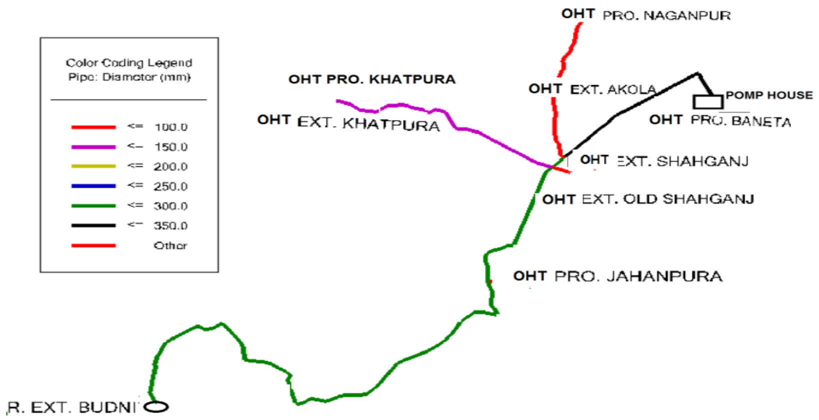

Fig.1 Clear water feeder network phase 1 Baneta

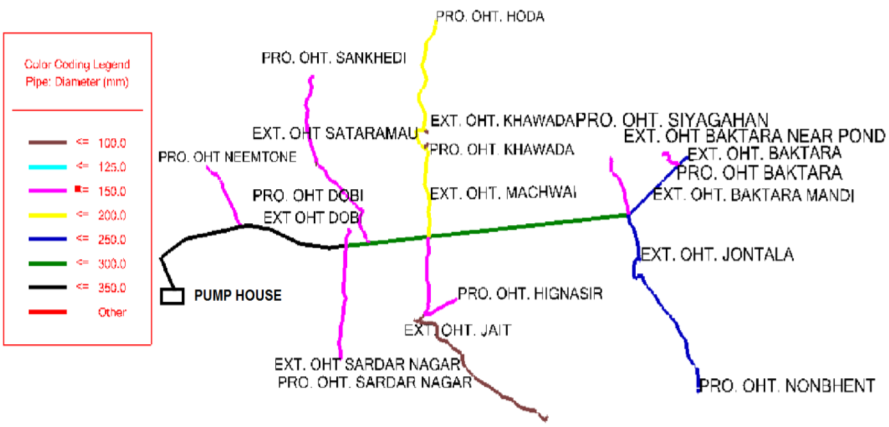

Fig.2 Clear water feeder network phase 2Baneta

IV. RESULTS AND ANALYSIS

The transient flow analysis is carried out by using Bantley water hammer software. Six different values of pump inertia are used for the analysis, which are obtained by varying the speed and power of the pump at a constant valve closure time of 5 seconds as shown in Table. 1 for phase 1 and 2 of feeder mains. The analysis was carried out in two parts.

A. Effects of pump inertia on maximum and minimum pressure in the different pipes of of the feeder network;

Table-1: Calculation for Inertia and Specific Speed for Phase-1

Case	Rotational speed in rpm	Power in KW	Flow in m^3/s	Head in m	Pump inertia in N-m^2	motor inertia in N-m^2	Total Inertia in N-m^2	Specific Speed in rpm
1	1450	109.464*	0.08678	72	11.3069	25.2763	36.5833	17.282178
2	1450	100	0.08678	72	10.3709	22.1102	32.4812	17.282178
3	1450	90	0.08678	72	9.3776	18.9178	28.2955	17.282178
4	2900	109.464*	0.08678	72	1.5500	9.0613	10.6114	34.564356
5	2900	100	0.08678	72	1.4217	7.9262	9.3480	34.564356
6	2900	90	0.08678	72	1.2855	6.7818	8.0674	34.564356

* Calculated capacity of pump for required 72 m head and 16 hours of pumping

Table-2:Calculation for Inertia and Specific Speed for Phase-2

Case	Rotational speed in rpm	Power in KW	Flow in m^3/s	Head in m	Pump inertia in N-m^2	motor inertia in N-m^2	Total Inertia in N-m^2	Specific Speed in rpm
1	1450	107.55*	0.085277	72	11.1179	24.6250	35.7430	17.1311
2	1450	100	0.086788	72	10.3709	22.1102	32.4812	17.2822
3	1450	90	0.086788	72	9.3776	18.9179	28.2955	17.2822
4	2900	107.55*	0.086788	72	1.5242	8.8278	10.3520	34.5644
5	2900	100	0.086788	72	1.4218	7.9263	9.3480	34.5644
6	2900	90	0.086788	72	1.2856	6.7818	8.0674	34.5644

*Calculated capacity of pump for required 72 m head and 16 hours of pumping

Table 1 and 2 shows the different values of pump and motor used for water hammer analysis.The maximum pressure obtained in all the pipes of feeder net work phase 1 and 2 are shown in fig.3 and fig.4. it is observed that the maximum pressures in all pipes in all cases are lesser than allowable maximum pressure for different pipe sizes as per IS 8329 (2000). So there is no need of surge tank in the pumping network [4,6]. The highest pressure is in pipe-11 which is just after the pump. The minimum pressure due to valve closure which higher than the vapour pressure. So there may not be column separation and bubble formation. There is no regular pattern for all.

B. Effects of Valve closure time (vct) on maximum and minimum pressure in the different pipes of of the feeder network;

In this case the valve closure time is changed to seven different values i.e. 2 sec, 3 sec, 4 sec, 5 sec, 6 sec, 7 sec, and 8 sec for a fixed value of pump inertia and its effects is observed in pipe as shown in figure-3 and figure-4. The pump capacity is constant as 109.464 KW for phase-1 and 107.55 KW for phase-2, which is the designed capacity of pumps.

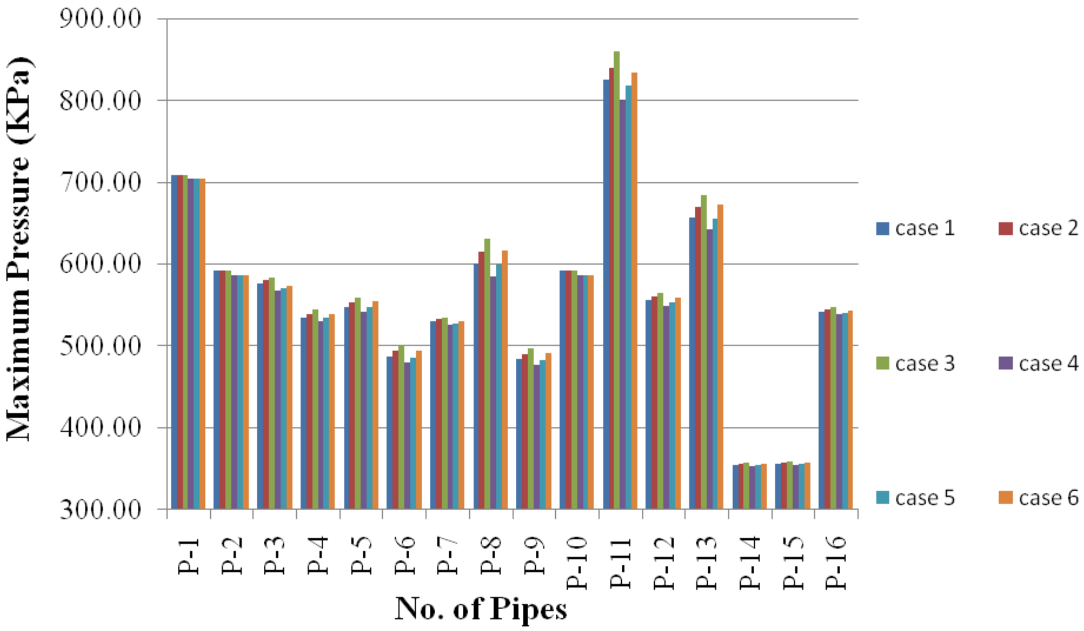

Fig.-3 Maximum pressure in different pipes due to change in pump inertia in Feeder network Phase-1

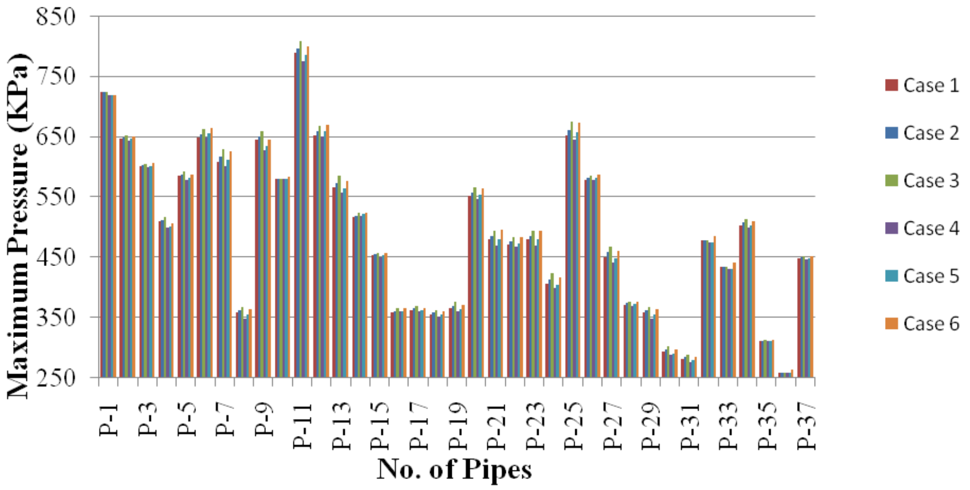

Fig.-4 Maximum pressure in different pipes due to change in pump inertia in Feeder network Phase-2

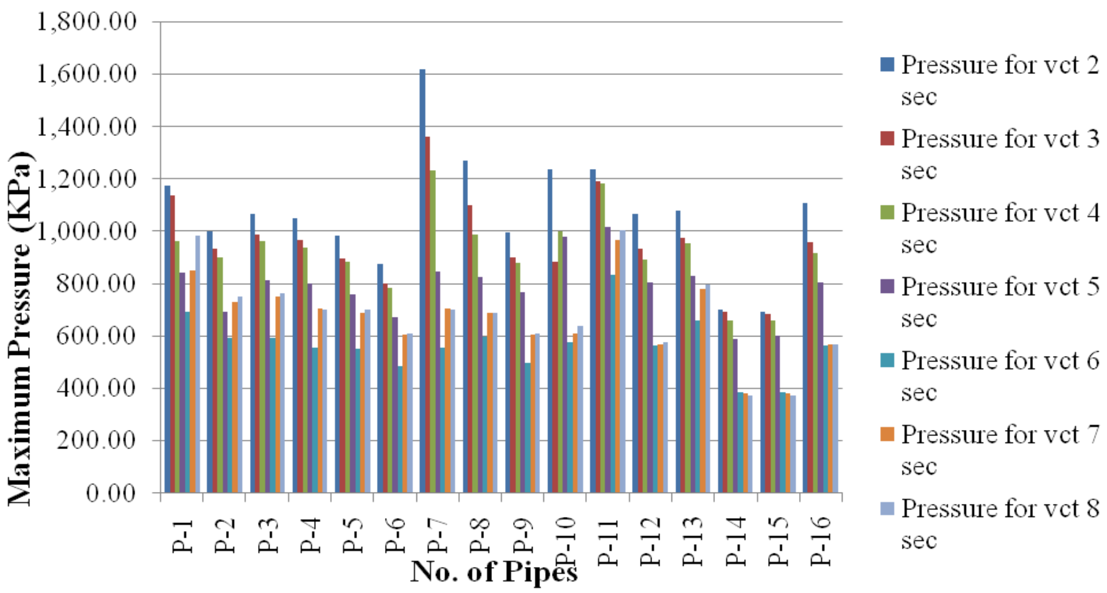

Fig.-5Maximum Pressure in different pipes at different valve closure time in Feeder networkPhase-1

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It is observed from fig.-5 and figure-6 that the maximum pressure in all the pipes is at control valve closure time as 2-8 sec which reduce with increase in valve closure time. The maximum pressure of the pipe is obtained in pipes- 7, 9, 10, 11, 12, 32, 34, and 37. As it can be observed from the pipe networks of both phase-1 and Phase-2 (figure-1 and figure-2) that the maximum pressure is achieved at pipes which are connecting the nodes of high elevation difference.

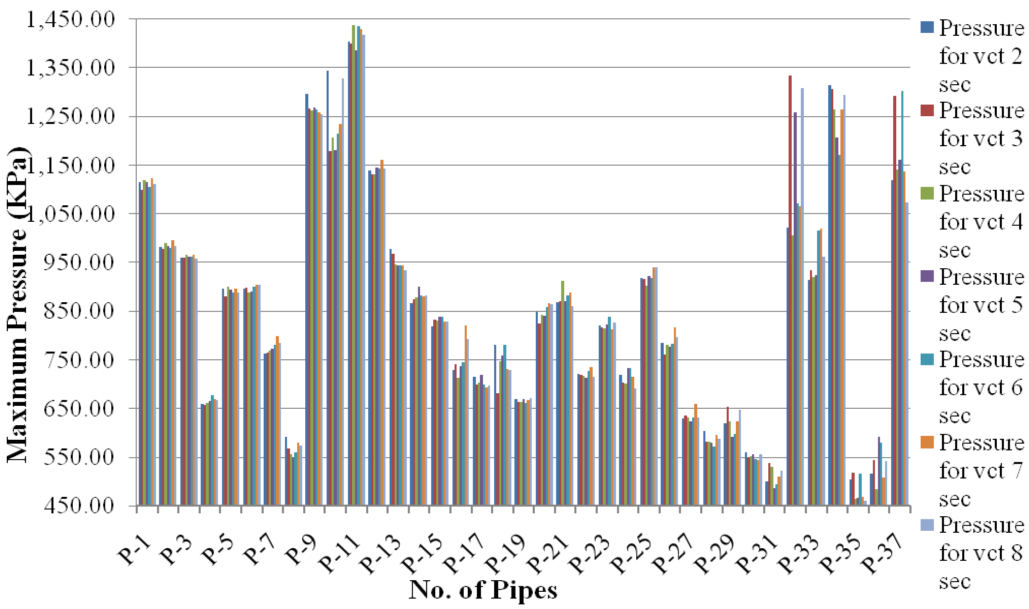

Figure-6 Maximum Pressure in different pipes at different valve closure time in Feeder network Phase-2

Time History of pressure for 60 sec total run time for one critical pipe of Phase-1

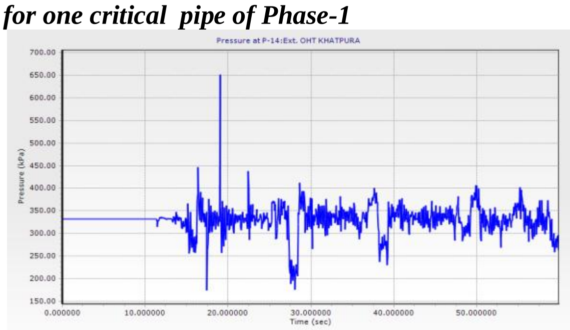

Figure-7 Pressure at pipe P-14 connected to Khatpura for valve closure time 2 sec

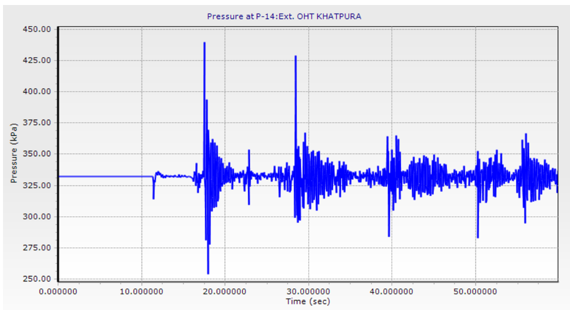

Figure-8 Pressure at pipe P-14 connected to Khatpura for valve closure time 5 sec

The pressure variations in P-14 is shown here because this pipe is having largest topographical variations which includes nearly 19m difference in elevation of U/s and d/s ends of the pipe. The pressure with total run duration time of 60 seconds for different calve closure time is shown in figure 7-9. It is observed that as the valve closure time is increased, the maximum pressure in pipe P-14 is decreased. The large pressure fluctuation is seen at the beginning and then it subsides with time. The maximum pressure is 650 KPa for valve closure time 2 sec, 437.5 KPa for valve closure time 5 sec and 339 KPa for valve closure time 10 sec. It shows that increase in valve closure time subsidised the maximum pressure.

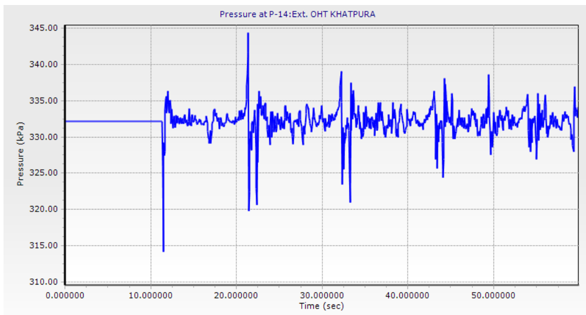

Figure-9 Pressure at pipe P-14 connected to Khatpura for valve closure time 10 sec

V CONCLUSION

Sudden shutdown of a pump, due to a failure of the pump or a failure of the electricity supply, can not be prevented. Depending on the consequences of a trip, it might be desirable to increase the inertia of the pump so that its rate of slowdown is reduced[9.10]. This can sometimes be done by fitting an over-sized motor or flywheel between the motor and the pump.

It can be observed the maximum pressure is greatly affected by pump inertia. As there is increase in pump inertia the maximum pressure increases in some of pipes but some pipes decreases. There is no regular pattern for all pipes. The maximum pressure at different pipes depends on pump inertia, pipe sizes and their locations in the networks.

The present study is helpful to study the effect of pump size and valve closure on the pressure and velocity distribution in the network which is very much useful to observe the pipe conditions during unforeseen power failure.

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