Air vessel instability

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Abstract
There are an increasing number of systems protected by massive banks of air vessels. Many of these are have connectivity that is inertially imbalanced.

There are stability issues associated with such installations. These issues may impinge on the safety function of the air vessel, but also on the control of initial charges in the vessels. This paper identifies the importance of inertial balance, and considers the implications air vessel balance on the surge protection.

1. Introduction

There now exist a significant number of major hydraulic systems protected by banks or air vessels in which inertial balancing has been ignored or considered irrelevant by the designers. This may be problematic for those systems themselves, but as these designs are copied the implications for other systems may be catastrophic. It is important that the significance of inertial balancing between vessels is considered.

This paper explains the difference between frictional and inertial balance and illustrates the implications the imbalance has for undermining the effectiveness of the protection system.

2. Imbalanced air vessels

The diagrams below shows two common examples of imbalanced air vessel installations contrasted with a balanced air vessel installation.

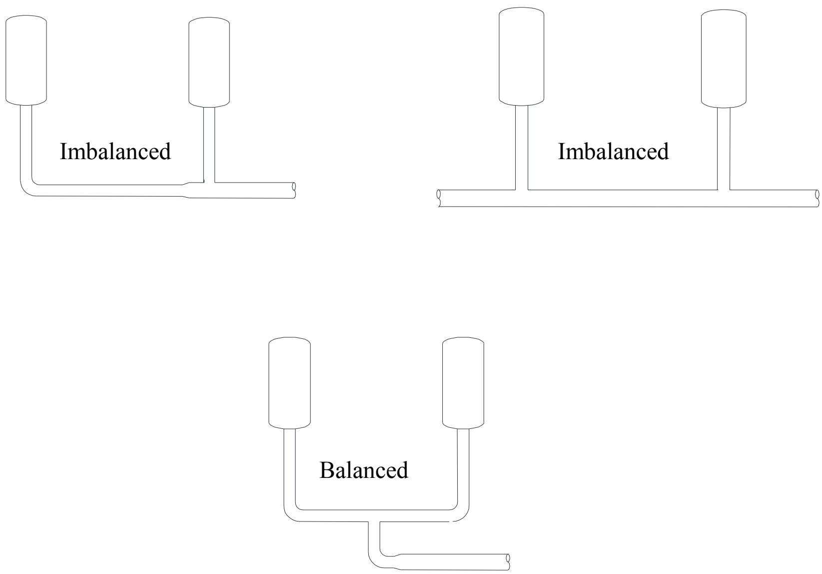

Figure 1 Examples of imbalanced air vessel arrays

In both of the imbalanced air vessel installations in Figure 1. inertial and frictional balancing is not achieved and there are potential stability and sizing issues associated with this imbalance.

3. Balanced hydraulic friction

Hydraulic designers are usually comfortable with the concept of frictional equivalence and so may address the balancing of air vessels in terms of balancing the friction down each flow path.

If the connections for multiple vessels are equivalent in terms of hydraulic friction, under steady flow conditions, flows from the branches would be equivalent if they had the same pressure differential. This is rarely the case.

A designer may attempt to achieve this friction balance in a system in which one vessel is connected to the main pipeline through a single length of pipe and a single elbow, by having another vessel with a shorter length of pipe connected with multiple elbows to balance the friction on the two legs.

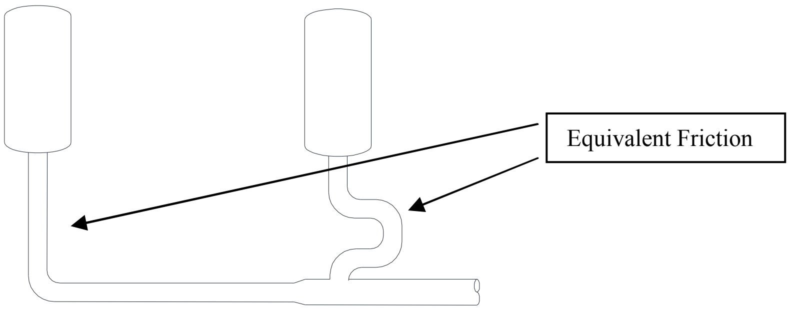

Figure 2 Friction balanced vessels

The vessels shown above may have equivalent friction down each of the connection parts, but the mass of water between each vessel and the main connection will be significantly different. The routes are equivalent in terms hydraulic friction, but not in terms of fluid mass: they are not inertially equivalent.

The result is that in spite of the friction balance, water will flow in and out of the shorter connection in preference to the long connection as the connecting fluid takes less time to accelerate and decelerate.

4. Impact on vessel performance

So how will this imbalance affect the performance of an air vessel installation? Well, it makes the behaviour of the vessel system significantly more complex, and in order to predict behaviour of an imbalanced system it is necessary to do very detailed modelling on the system of air vessels and the pressure surge scenarios that occur in the system.

To demonstrate the implications of imbalanced air vessels, a system that has been protected by a balanced air vessel solution was modelled using an imbalanced bank of imbalanced air vessels in a formation as shown below.

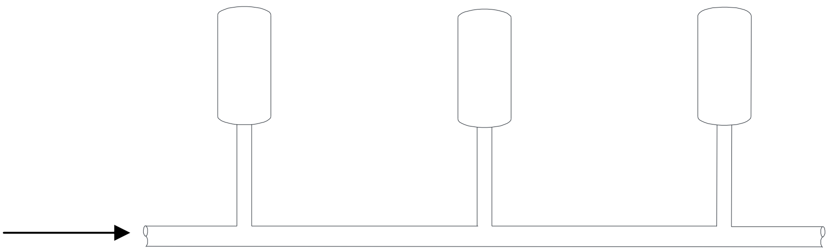

Figure 3 Imbalanced air vessel array

The modelling was carried out using a method of characteristics transient model of the system in which the 24m length intermediate pipes between the vessels are modelled as elastic pipes. This is essential to represent the imbalanced behaviour of the vessels. Many designers in error model these as rigid pipes; an approach which would totally misrepresent the imbalance.

The chart below shows the simulated air volume levels in the imbalanced multiple air vessels.

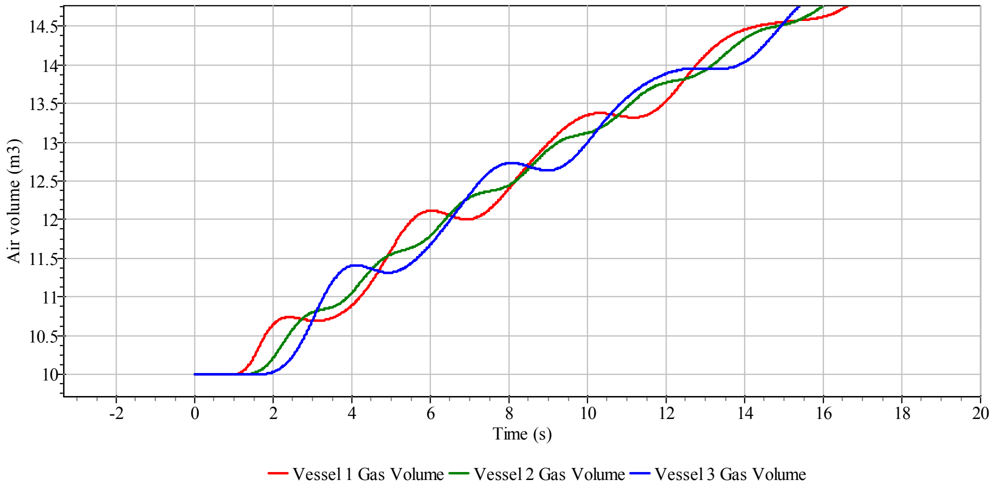

Figure 4 Air volume histories for imbalanced vessel array

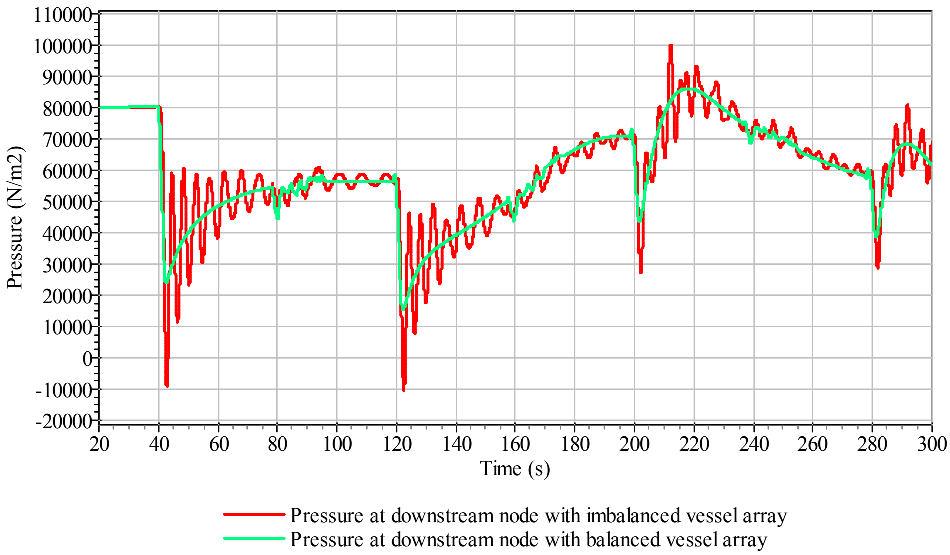

Figure 5 Pressure history at downstream node for balanced and imbalanced vessel solutions.

Figure 4. illustrates the volume change in each vessel and shows clearly the imbalanced flow from the vessels. The degree of imbalance will depend on both the degree of geometric imbalance, and the nature of the transient event. Each transient event will generate a different imbalanced response and oscillation between the vessels.

Figure 5. compares the pressure trace at a position 19km downstream for a system with a balanced vessel system with an imbalanced system. The chart shows that the flow oscillations between the vessels result in pressure oscillations which undermine the effectiveness of the vessels.

So imbalanced air vessels will be less effective at preventing surge events than balanced vessels. It will be difficult and sometimes impossible to control initial air volume settings reliably. Predicting the performance of imbalanced air vessels will require the consideration of a wider range of scenarios than would normally be considered in a surge analysis. The analysis will require intermediate pipes to be analysed elastically so will require very small timesteps to predict the imbalanced behaviour.

5. Inertial Balancing

In order to achieve inertial balancing, it is important the all routes from the multiple air vessels have the same mass and acceleration (determined by the diameter and length of the connection). Examples of inertially balanced air vessel arrays are shown below.

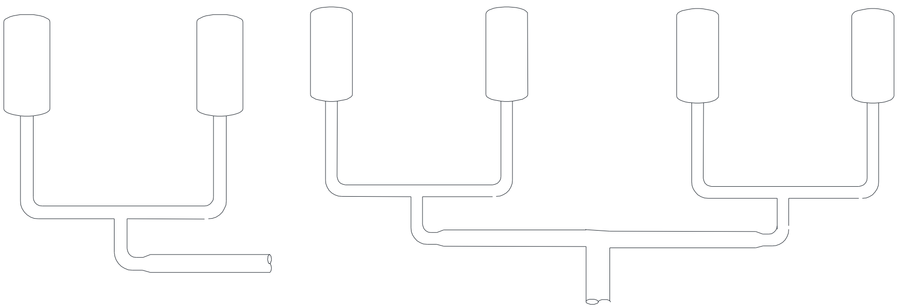

Figure 6 Examples of inertially balanced vessel arrays

6. Air side balance tubes.

Some designers identify severe control issues with inertially imbalanced vessels and attempt to address these through the provision of air side balance tubes.

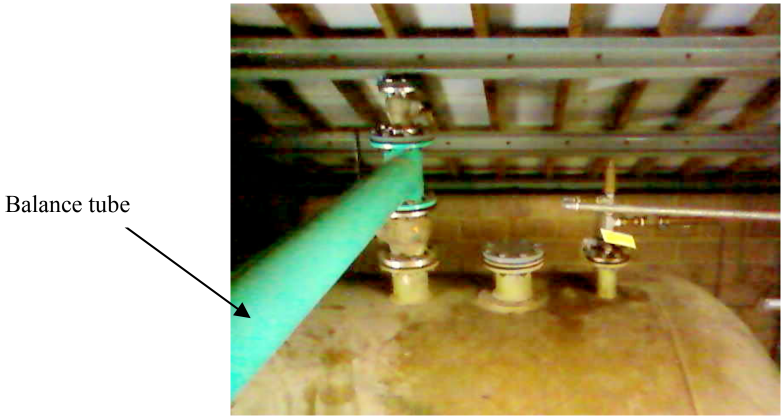

Figure 7 Photo of Balance tube by courtesy of Ian Currie of Quantum Engineering

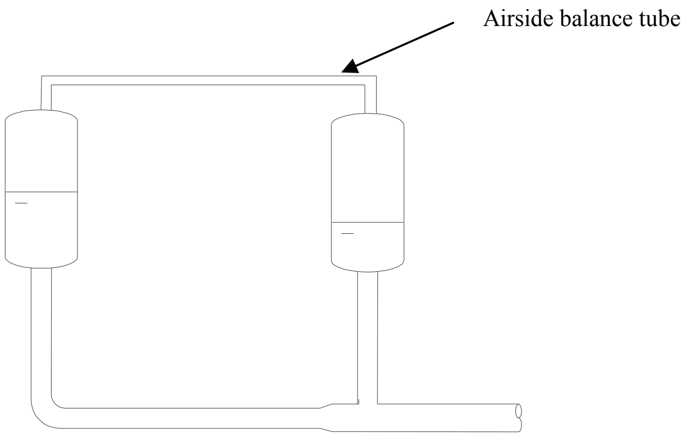

Figure 8 Airside balance tube - redundant if vessels are balanced and disastrous if they are imbalanced

The idea behind this solution is that it maintains a common pressure in all of the vessels.

This however, can be problematic. While it might balance pressures between the vessels, it will not balance volumes, and will increase the flow imbalance between the vessels as the fastest discharging vessel will not have a proportional air pressure drop to counter.

The air side pressure tube will therefore significantly exacerbate the volumetric imbalance between the vessels and would therefore be of questionable value in an imbalanced air vessel system, and redundant in a balanced system.

7. Other Problems

As many designers seem to be unaware of the phenomenon of inertial imbalance, many of these imbalanced air vessel systems are served with only a single level control in one of the air vessels and a single pressure transducer on that vessel. The result of this is that operations staff are unaware of the actual volumes in the other vessels, and of this phenomenon on inertial imbalance between vessels.

8. Conclusions

This paper has illustrated the concept of inertial imbalance in an air vessel array. The paper has illustrated that this inertial imbalance can have a detrimental impact on the effectiveness of the air vessel array.

It is therefore strongly recommended that wherever possible, air vessel arrays should be inertially balanced.

However, there may be significant cost implications associated with constructing inertial imbalance in a large vessel array, and it may be necessary to consider the implications of an imbalanced array.

If inertial imbalance is to be tolerated in an air vessel array, a detailed design evaluation is required in which the imbalanced fluid columns are modelled accurately and for a wide range of transient and potential imbalance exciting scenarios.

It is essential that the imbalanced fluid columns are modelled as elastic pipes and not rigid columns otherwise the modelling will not reliably predict the behaviour of the air vessels.

An imbalanced array will require levels and pressures in all of the vessels to be measured independently as it cannot be assumed that they will be equal.

Air side balancing tubes can significantly exacerbate the imbalance.

9. Acknowledgements

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