PRESSURE MONITORING ND SAFETY SYSTEMS

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1. Introduction

The paper presents the experimental setup in Laboratory for Process Measurement comprising of test chamber emulating the enclosure to be protected, air source, pressure sensor, and precision pressure controller. The aim of the test setup is to, seemingly for the first time, experimentally investigate the behavior of pressure monitoring ND safety systems. The preliminary results show that the intrusions are clearly detectable even in the case of a passive pressure system.

For the sake of completeness the paper also presents the scope and classification of ND pressure monitoring in humanitarian safety and other safety systems. Possible applications include: pressurized suits (aeronautics, space, biological and chemical protection, diving), pressurized chambers and rooms (laboratories, pressurized biological or chemical chambers, safe boxes and vaults, protected premises), as well as pressurized apparatus and pipe or duct systems (gas pipelines, gas and vapor ducts, etc.) which should be monitored for reasons of humanitarian safety.

According to Blaise Pascal-s law, the static pressure spreads evenly in all directions meaning that pressure disturbance in the domain can be sensed by a single pressure transducer located anywhere in the domain. In case of domain protection the monitoring of the pressure has several other advantages: the pressure field is invisible and the maintenance of pressure field is simple and low-cost. The first-choice pressure medium (air) is free and readily available. Other gases as nitrogen or argon can be applied to smaller domains and can also be intrinsic to some applications as it is the case in food preservation, pharmaceutical industry and packaging. When transporting hazardous materials, human and environmental safety can be increased by ND pressure monitoring of the under-pressurized inner container by means of low-cost, miniature and battery powered pressure transducer/monitor.

2. Methodology and basic architectures

The ND pressure monitoring is based on the fact that any intrusion or movement in the protected space or around objects results in the pressure change that can be detected. In elliptic situation [1], meaning enclosures with static or nearly static flow conditions the pressure sensor can be placed in any point of that space. In the parabolic type of flow [1], meaning strong flow components in one direction where convection dominates conduction, as it is in tubes, corridors or ducts, the pressure sensor must be placed downstream from the intrusion point. Simply speaking the opening of the door of a room will be detected in any point of that room while the disturbance or contamination of air in a duct can be better detected downstream from that point.

The theoretical basis for the pressure monitoring safety systems is generally provided by the Navier-Stokes and continuity equation [2]. The compressible flow of gas (air) at any place in the monitored continuum in Cartesian coordinates is defined by values of three velocity vectors and the scalar value of pressure. For those four unknowns the four conservation equations are available: the three momentum [2] and one continuity equation. There is no equation for pressure – it is implicit in all four equations: if the correct pressure field is fed into the momentum equations, the resulting velocity field will satisfy the continuity equation. This means that the dynamic pressure and air velocity monitoring are implicitly coupled.

Furthermore for the purpose of ND pressure monitoring the incompressibility assumption is welcome and readily applicable in safety systems where monitored air velocities dwell way below the velocity of sound in air. This assumption leads to significant simplification of the momentum equations and continuity equation. If axially symmetric (cylindrical or annular), two dimensional (spaces between walls or plates), or one-dimensional (pipelines, etc.) geometries are monitored, the mathematical models are further simplified. Therefore the theoretical basis for the numerical modeling of the pressure field in the protected areas or around protected objects is reliable and today's numerical methods and computers can provide for fast and reliable solutions. Those solutions can be used in design stages to provide for algorithms which will detect anomalies in the monitored pressures and trigger the necessary response.

Since the focus of this paper rests on pressure monitoring safety systems, the reader is referred to [3], [4], [5] for methods on modeling of the pressure/velocity fields.

At the first glance the pressure monitoring systems can be grouped as natural pressure systems or as forced pressure systems. In the first group the existing (atmospheric) pressure in the protected enclosure (suit, room, etc.) is monitored by the sensitive pressure measuring system to detect various events including opening or breaking of doors, windows or unauthorized movement of objects. In the forced pressure method the protected enclosure is slightly over-or under-pressurized in respect to the atmospheric pressure. Then the pressure measuring system is used to detect changes of pressure which could be associated with safety threatening events. But there are many more classifications parameters and the safety systems based on ND pressure monitoring could be generally classified:

– By the way pressure in the protected area is maintained for the purpose of the ND pressure monitoring [Figure 1] as: passive or active pressure monitoring systems,
– By the level of the monitored pressure as atmospheric or gauge pressure (forced) systems
– By the way the pressure is spatially distributed in the protected domain as: homogeneous or non-homogeneous.
– By the way the pressure changes with time as: steady-state or dynamic.

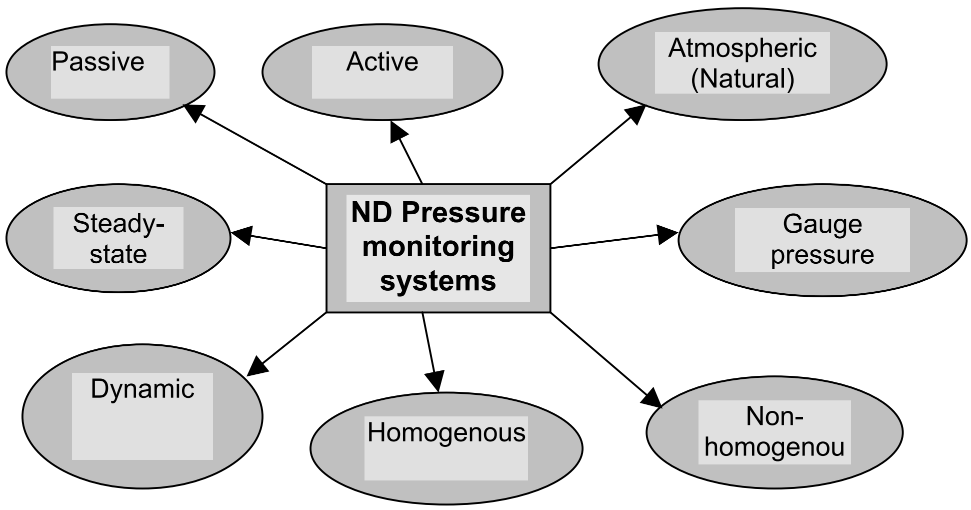

Figure 1: Classification of ND Pressure Monitoring systems

2.1 Passive ND pressure monitoring systems

The systems that rely on existing, application dependent pressure are designated as

Passive pressure monitoring systems. What is important here is that energy input to the system for pressurization is demanded by the process itself and is not the consequence of ND pressure monitoring. Here the application-dependent pressure can be atmospheric or the system can be at positive or negative gauge pressure.

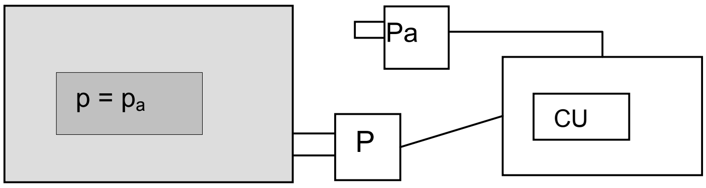

Figure 2: Passive atmospheric ND pressure monitoring system

In Figure 2 the existing (atmospheric) pressure in the protected enclosure (room, vault etc.) is monitored by the sensitive pressure transducer (P) connected to the control unit (CU). After some tuning and with the aid of adaptive algorithm the control unit can detect various events including opening or breaking of doors, windows and trigger pre-defined response. The additional transducer (Pa) monitoring the external atmospheric pressure could facilitate differentiation from sudden external changes induced by wind gusts or movement of large vehicles.

Typical passive gauge pressure safety monitoring system is depicted in Figure 3.

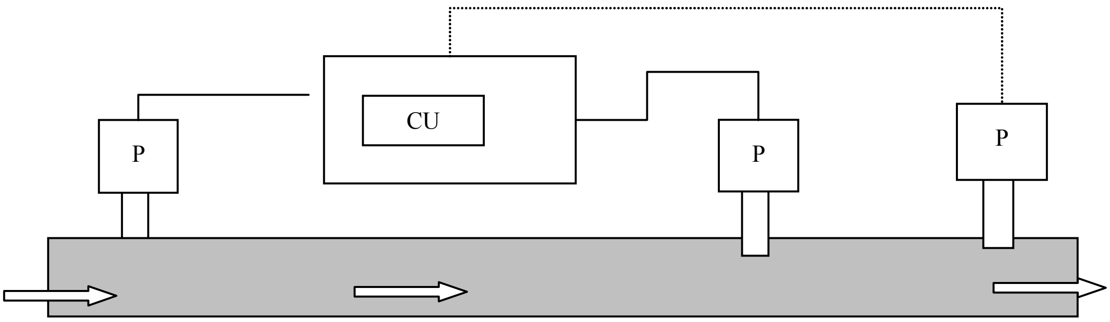

Figure 3: Passive gauge pressure ND pressure monitoring system

Two pressure transducers (P) connected to the control unit (CU) are monitoring existing pressure difference in a air duct caused by the constant (and flow dependent) pressure loss. Upon any obstruction, movement or intrusion in the duct, causing the pressure perturbation, the control unit, with the aid of pre-tuned and adaptive algorithm, can trigger the pre-defined response. The use of the third transducer could facilitate differentiation from the change-of-flow-induced pressure loss. For any given flow this is also an example of static but non-homogenous pressure system due to the existence of flow-induced pressure gradient along the duct.

2.2 Active ND pressure monitoring systems

The active monitoring systems use energy external to the process to over- or under-pressurize the protected domain in respect to the atmospheric pressure. This positive or negative gauge pressure is then monitored to detect changes of pressure which could be associated with safety threatening events.

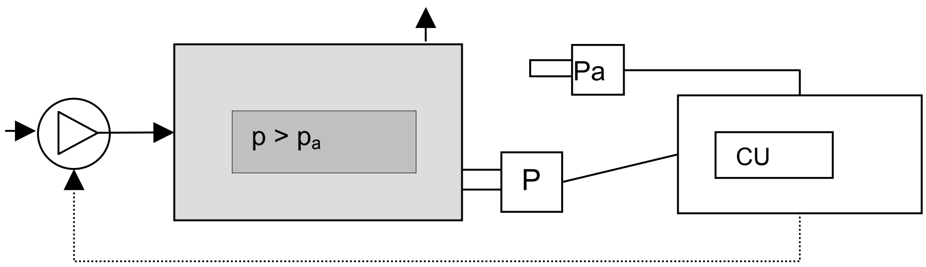

Figure 4: Active ND pressure monitoring system

The monitored domain in Figure 4 is slightly pressurized in relation to the surrounding atmosphere, by means of a radial fan. In this way the clean-room-like condition is created and maintained. Any attempt to enter the protected domain (opening of doors or windows, etc.) would produce immediate corresponding pressure variations. The transducer (P) connected to the control unit is used to detect those changes which could be associated with safety threatening events. With the aid of another transducer the control unit can compensate for sudden changes of external atmospheric pressure and adjust the gauge pressure accordingly by controlling the radial fan. This is also an example of steady-state and homogenous pressure system. In the case of dynamic system, using the similar configuration as in Figure 3, the fan would be regulated to produce gradually changing or oscillating (for example sinusoidal) pressure. The amplitude and periods of the pressure oscillation are then used to improve resolution and repeatability of detection.

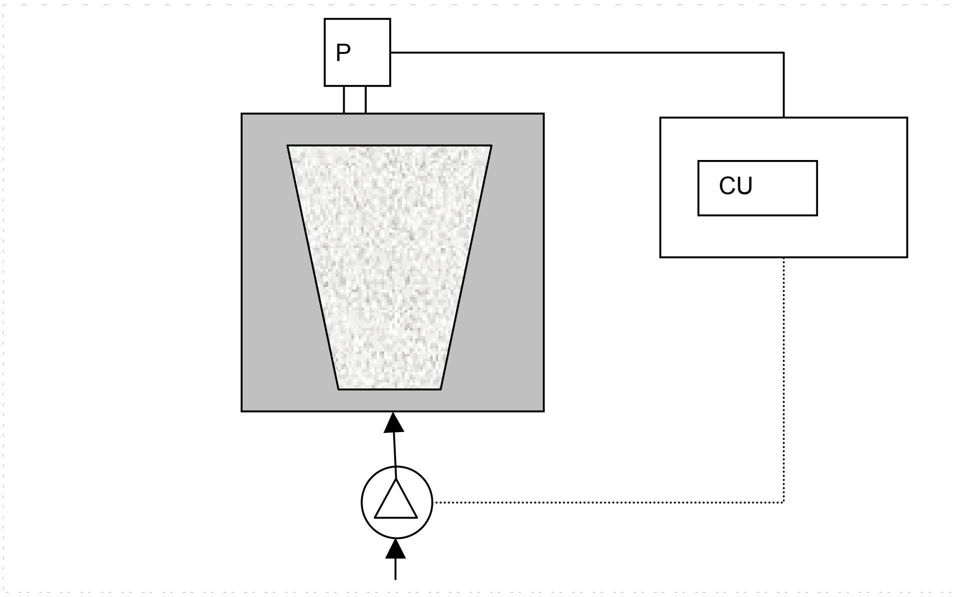

Figure 5: Non homogenous pressure monitoring system

The non-homogenous steady-state methodology is presented in Figure 4. The radial fan is producing a jet of air which impinges on the pressure sensor (P). The configuration resembles the widely used air-curtains which can be placed anywhere in the protected domain. The velocities in the jet core are determined by the application-dependent reaching distance of the jet and by the entrainment characteristics of the jet which are the consequence of the shape of the jet. The core velocities are in principle low and where more space has to be covered several jets can be used instead of increasing the jet velocity. Any disruption of the invisible jet is detected by the transducer (P) and fed to the control unit (CU) for processing. In the dynamic variety the jet is pulsed.

3. Experimental setup and results

Experimental Setup (Figure 6) in Laboratory for Process Measurement was constructed with the aim to investigate and quantify the pressure disturbances associated ND pressure monitoring in chambers and rooms (i.e laboratories, biological or chemical chambers, safe boxes and vaults, protected premises).

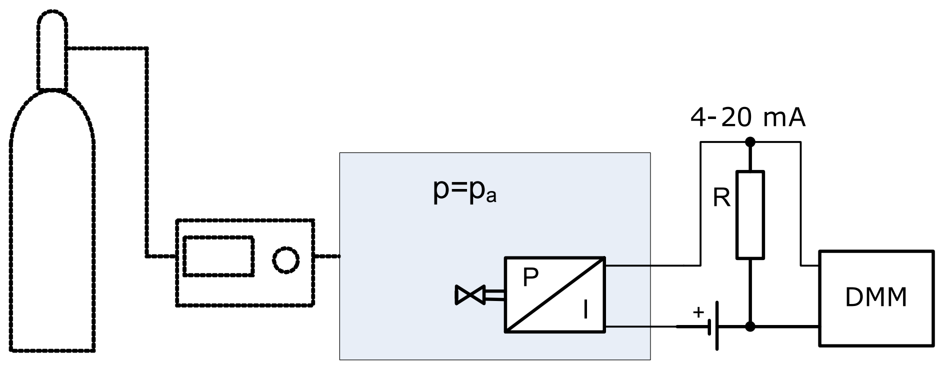

Figure 6: Experimental setup

The system depicted in Figure 6 can be used to simulate passive (atmospheric) or active (positive and negative gauge pressure) as well as static or dynamic ND pressure monitoring systems. In general the gas (air or nitrogen) from compressed source is fed into the precision pressure controller/regulator which can be computer-controlled via RS-233 or IEEE ports. The pressure regulator controls the gas pressure in the air-tight steel chamber resembling a medium sized vault with a door completely opening one side. The low pressure differential/gauge sensor is placed in the chamber and its 4-20mA output is connected to the 7 1/2 digit multi-meter via precision electrical resistance. In this way the voltage drop over known resistance value is measured to obtain values of the electrical current.

The preliminary investigation was carried out in the passive and atmospheric scenario meaning that the air pressure in the chamber was kept at the steady-state atmospheric level. In this case there is no pressure difference between the enclosed space and the surrounding environment and any intrusions are bound to produce the lowest pressure disturbances as compared to other types of ND monitoring systems described above.

To simulate pressure disturbances the vault door was opened and closed with low, medium and high velocities closely resembling the human intrusions in the corresponding states of urgency. The operation for all three velocities was repeated several times and the average values are presented in the Figure 7 and in Table 1.

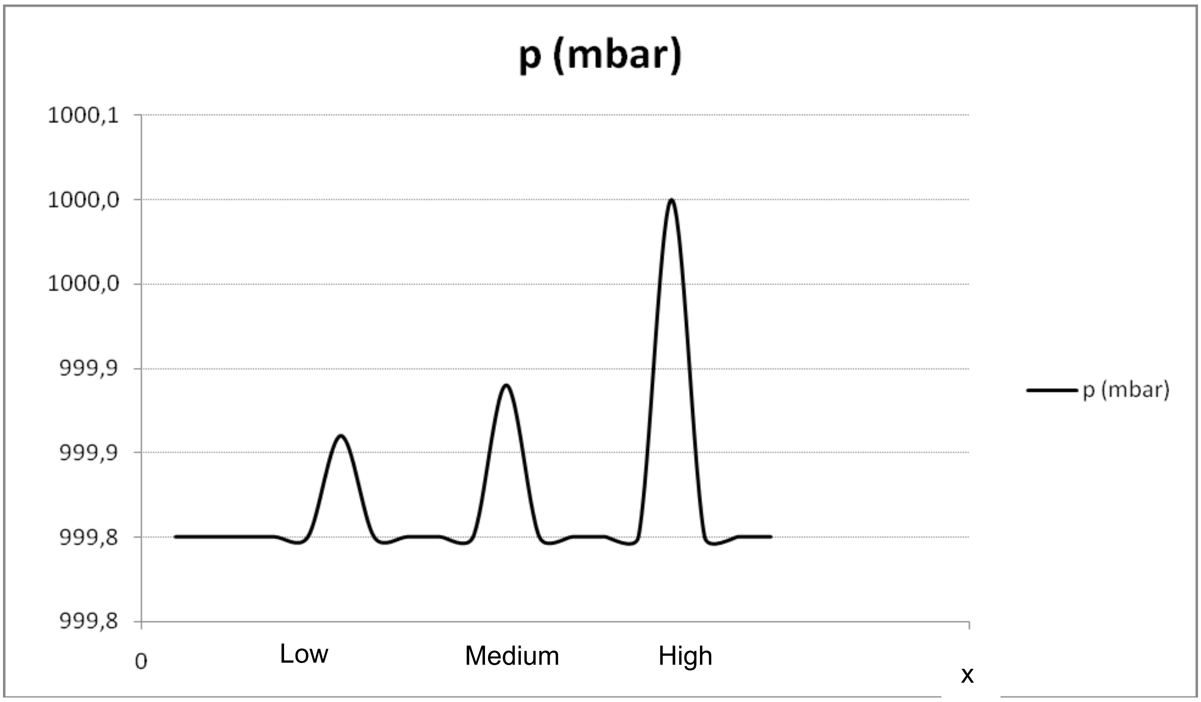

Figure 7: Pressure disturbances corresponding to low, medium and high velocities

Door opening velocity	$p-p_a$ [Pa]
Low	6
Medium	10
High	15

Table 1: Average values of pressure disturbances

Even in the case of the passive atmospheric system it can be seen that the resulting disturbances are clearly detectable and that their amplitudes depend on the opening velocities.

3. Conclusion

As opposed to optical, thermal vision and other similar methods and means for search and surveillance, the pressure monitoring ND safety systems are unknown to the terrorists groups and practically undetectable prior to their activation.

ND pressure monitoring in humanitarian and other safety systems has several advantages:

– The pressure disturbance is sensed by single transducer paced anywhere in the domain.

– The disturbance propagates in the protected volume at velocity that is close to the speed of sound in gas.

– The pressure field is invisible.
– The maintenance of pressure field is simple and low-cost.
– The obvious pressure medium (air) is free and readily available,
– Other gases (as nitrogen or argon) can be applied serving also other purposes,
– Simple ND pressure monitoring in transportation is possible by means of battery powered pressure transducer/monitor.

The variety of methodologies utilizing different modes of pressure maintenance, its behavior in time, spatial distribution and level of pressure enable safety system design suitable for specific applications as: active or passive, steady-state or dynamic, homogenous or non-homogenous and natural or forced.

To experimentally investigate the behavior of pressure monitoring ND safety systems, the experimental setup in Laboratory for Process Measurement was presented. Its main parts are the test chamber emulating the enclosure to be protected, air source, pressure sensor, and precision pressure controller. The preliminary results of measurements for the case of passive atmospheric system and for the cases of the vault door being opened and closed with low, medium and high velocities closely resembling the human intrusions were presented. The resulting disturbance amplitudes are at the level of 5, 10 and 15 mbar depending on the opening/closing velocities. This means that the intrusions are clearly detectable even in the case of a passive pressure system.

Future work on the test setup might address identification of pressure disturbances related to specific activities in protected domains as well as quantification of disturbances in other types ND monitoring systems.

References

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