DOI 10.5162/SMSI2020/P2.1

Explosion Pressure Measurement and Thermal Shock

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Summary:

Transient thermal loads on piezoelectric pressure sensors as a result of an explosion lead to a heat flux which results in a reduction of the measured pressure amplitude as well as an increase of the scatter of the measurement results. The effects of this so-called thermal shock depend on the type of sensor and can be reduced by suitable measures, e.g. thermal protection layers of RTV (Room-Temperature-Vulcanizing) silicone.

Keywords: flameproof enclosures, explosion pressure, piezoelectric pressure sensor, thermal shock, thermal protection

Introduction

Information on the maximum pressure rise time and the maximum pressure of explosions is needed to assess the effects of explosions and to evaluate safety measures to prevent explosion accidents [1]. The analysis of a recent international proficiency testing program has shown that all the participants involved use piezoelectric pressure sensors to measure pressure signals over time. Furthermore, it turned out that one of the main reasons for the scattering of the results was the missing or insufficient protection of the sensor membrane against temperature influences [2].

The influence of thermal effects on piezoelectric pressure sensors during cylinder pressure measurement in combustion engines is a subject of frequent investigations and publications [3, 4]. This involves many explosions per minute leading to a nearly static thermal load on the pressure sensor which results in a thermal zero shift and thermal sensitivity change [5]. In the case of individual explosions, such as those occurring during type testing of flameproof enclosures [6], the explosions occur with rapid temperature changes. Here, the temperature gradient error, the so-called thermal shock, causes the greatest thermal load. For this application there are only very few studies and publications carried out so far [7]. This led to the motivation of this work to conduct further investigations regarding the influence of the thermal shock and measures to prevent it in this specific field of work.

Experimental set-up

In this work a spherical enclosure made of stainless steel with a volume of 10 l is used. The fuel-air mixture consists of 31 Vol-% H_2 in air in accordance with IEC 60079-1 [6]. The mixture is ignited by two electrodes in the center of the sphere. Thirteen piezoelectric pressure sensors of different types and sensor designs to be tested are mounted flush in brass adapters in the housing wall. To increase the statistical significance, at least two sensors of the same type were used. Furthermore, a heat flux measuring sensor in the design of a pressure sensor is installed to determine the heat flux. The explosion pressure measurements and heat flux determination are each performed with and without preparation to prevent thermal shock. The preparation material used consists of a 1 mm RTV silicone layer which is applied to the sensor membrane.

Results

The results in Fig.1 compare different piezoelectric pressure sensors with and without preparation against thermal shock. The explosion pressures are normalized to the highest mean explosion pressure p_{max} = 7.59 bar by sensor S7. This work focuses on the Kistler 6031 and Kistler 601CAA sensors, as these are used very frequently by testing laboratories. The other ones are only shown for overview to demonstrate the variety of the possible sensors to be used and to show the differences in thermal shock behavior. It can be observed that for eight of the thirteen pressure sensors (S4, S5, S7, S8, S9, S10, S11 and 6031) the measured explosion pressure without applied RTV silicone drops significantly compared to the measured values with 1 mm RTV silicone. For the remaining five pressure sensors (S1, S2, S3 S6 and 601CAA), the measurements with and without RTV silicone are consistent within the measurement accuracy.

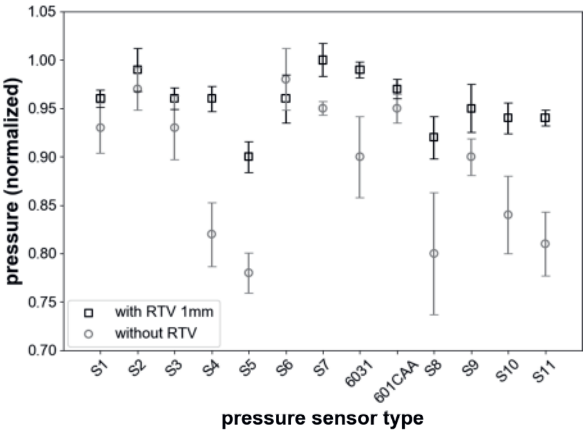

Fig.1. Comparison of different pressure sensor types with and without thermal protection (RTV silicone).

Furthermore, it can be observed that the scatter of measured values for eleven pressure sensors without RTV silicone is higher than with applied RTV silicone.

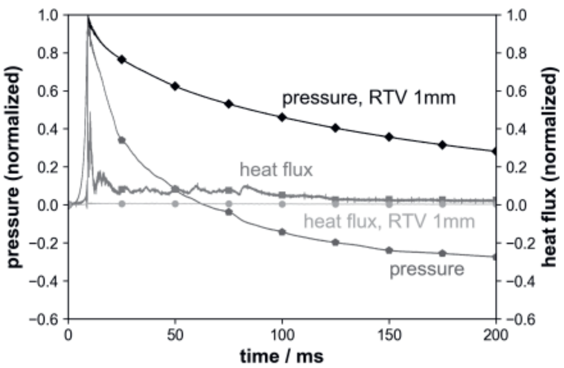

Fig.2. Pressure curves and heat flux graphs for 601CAA sensor with and without RTV silicone.

Fig. 2 shows the pressure curves over time for the 601CAA sensor and the associated heat flux for both cases, with and without RTV silicone. No effect of thermal load is visible in the range of pressure rise. But as soon as the flame front reaches the sensor, clear differences can be observed. The deformation of the membrane as a result of the heat flux results in a force that opposes the pressure force. In the case without thermal protection, the heat flux increases rapidly leading to a slight reduction of the pressure amplitude as can be seen in Fig. 2. Afterwards the pressure signal drops significantly. In contrast, no significant heat flux can be measured when using thermal protection.

Conclusions

Due to the rapid temperature rise caused by an exothermic explosion, a pressure measurement is influenced for this application by dynamic temperature loads. Each type of pressure sensor is affected differently by the thermal shock. The intensity of the reaction depends mainly on the design of the sensor, especially that of the membrane. If the membrane is designed so that it neither stretches nor compresses the piezoelectric crystal of the pressure sensor when deformed due to thermal load, the effects of the thermal shock can also be reduced (see 601CAA in Fig.1). Nevertheless, it can be stated that almost all piezoelectric pressure sensors react to thermal shock, which has a negative effect on the actual explosion pressure measurement. When determining explosion pressures, it is therefore recommended that the pressure sensors used be protected against the influence of the thermal shock. The use of 1 mm RTV silicone has proven to be an appropriate measure to reduce the heat flux into the sensor which prevents an interference with the measured pressure signal and additionally reduces the scatter of the measured values.

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