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"Gheorghe Asachi" Technical University of Iasi, Romania

INFLUENCE OF ELECTRIC MOTORS DESIGN ON THEIR BEHAVIOUR DURING TESTING IN EXPLOSIVE MIXTURES

Mihai Magyari*, **Sorin Burian, Lucian Moldovan, Dragoş Fotău, Marcel Rad**

National Institute for Research and Development in Mine Safety and Explosion Protection - INSEMEX, 32-34 G-ral Vasile Milea Street, Petrosani, Hunedoara, Romania

Abstract

The research carried out in the specialized Laboratory of the National Institute for Research and Development in Mine Safety and Explosion Protection - INSEMEX Petrosani has identified the causes of high pressure peaks occurrence in the case of large electric motor enclosures as: the extremely large internal volume, the geometrical shape of motor enclosures and the very intricate and complex internal arrangement of such motor enclosures, having in mind the tendency of motor manufacturers for chemical and petrochemical industry to manufacture motors having more complex geometrical shapes.
These results proved to be very useful in assisting designers of large flameproof electric motors to improve motors design so as to make them more reliable when testing in explosive mixtures.

Key words: electric motor, explosive atmospheres, flameproof enclosure, pressure, pressure pilling

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1. Introduction

The purpose of the paper is to study the way in which the internal volume, the dimensions, the geometrical shape, as well as the internal arrangement of explosion protected flameproof large rotating electrical machine enclosures influence the maximum explosion pressures and the explosion pressure development, when tested in explosive mixtures of gases and vapors. This research has proved to be very useful in assisting designers of large flameproof electric motors to improve the motors design in order to make them more reliable when tested in explosive mixtures, as it is not yet very clear to what extent the above mentioned elements influence the explosion pressure development when testing these motors in explosive mixtures, for certification purposes.

The electric motors with flameproof enclosure protection type have to withstand the following tests and verifications, in order to be certified for placing on the market (GD, 2016; SR EN 60079-0, 2013; SR EN 60079-1, 2015):

- determination of reference pressure and tests for overpressure;
- tests for non-transmission of an internal ignition.

The most important subassemblies of flameproof enclosure motors that provide the type of protection Ex d are: stator casing, shields, rotor, fan and fan hood, terminal box, terminal box cover, as shown in Fig. 1.

2. Research methods used

The basic testing methods used in the laboratory are:

a) Determination of the maximum explosion pressure (reference pressure) that can be developed inside the motor enclosure, depending on the group/ subgroup of gases for which the motor is designed (SR EN 60079-1, 2015). All motors are tested in laboratory using three pressure transducers, as well as three ignition

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[*] Author to whom all correspondence should be addressed: e-mail: mihai.magyari@insemex.ro; Phone: + 40 254541621; Fax: +40 254546277

devices, each located in the end-turn area at each end of the motor and under the terminal plate of the terminal box. Fig. 2 shows a typical example of an explosion pressure diagram, using three pressure transducers diagram.

For normal enclosures, the explosion pressure develops reasonably uniformly through the enclosure. However, when an enclosure incorporates some form of restriction between the two parts, the situation changes (Munro, 2017). When an explosion occurs on one side of the restriction, the gas or vapor on the other side is compressed prior to ignition by the flame front. This leads to a higher pressure when no restriction is present (Munro, 2017).

Based on our experience (research conducted in the specialized laboratory of INSEMEX), we found that the maximum explosion pressure is often recorded under the terminal plate of the motor to the pressure pilling phenomenon. Ignition is initiated at each end of the motor and under the terminal plate, in both situations: when the motor is off and when it is running.

The term "pressure pilling" as used in this paper, refers to a pressure increase in one of the motor enclosure compartments, above the values normally expected to occur in that compartment, if that subdivision did not exist. This increase of the explosion pressure can be considered abnormal, as compared to the pressure resulted from a burning process in constant volume, having an initial pressure of the testing mixture equal or almost equal to atmospheric pressure (Magyari, 2015, 2017). Fig. 3 shows an example of explosion pressure diagram where very high explosion peaks have been observed during testing of a large motor.

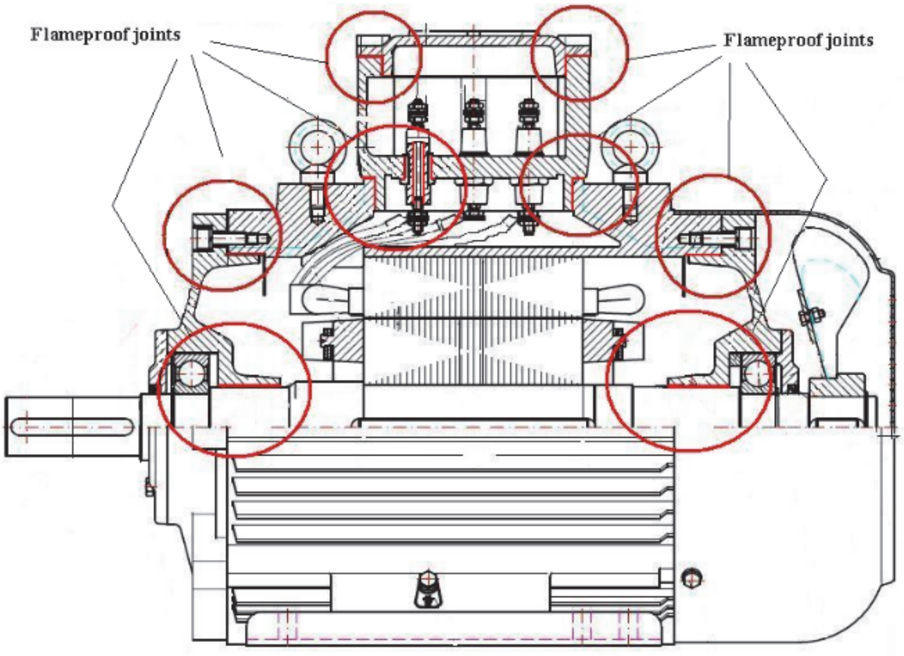

Fig. 1. Flameproof enclosure motor assembly

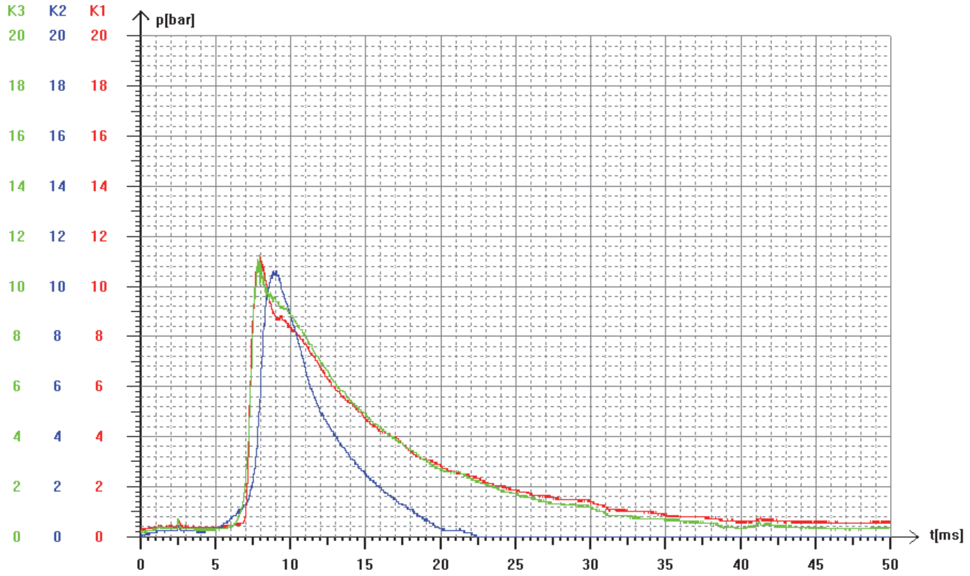

Fig. 2. Example of explosion pressure diagram, using three pressure transducers setup

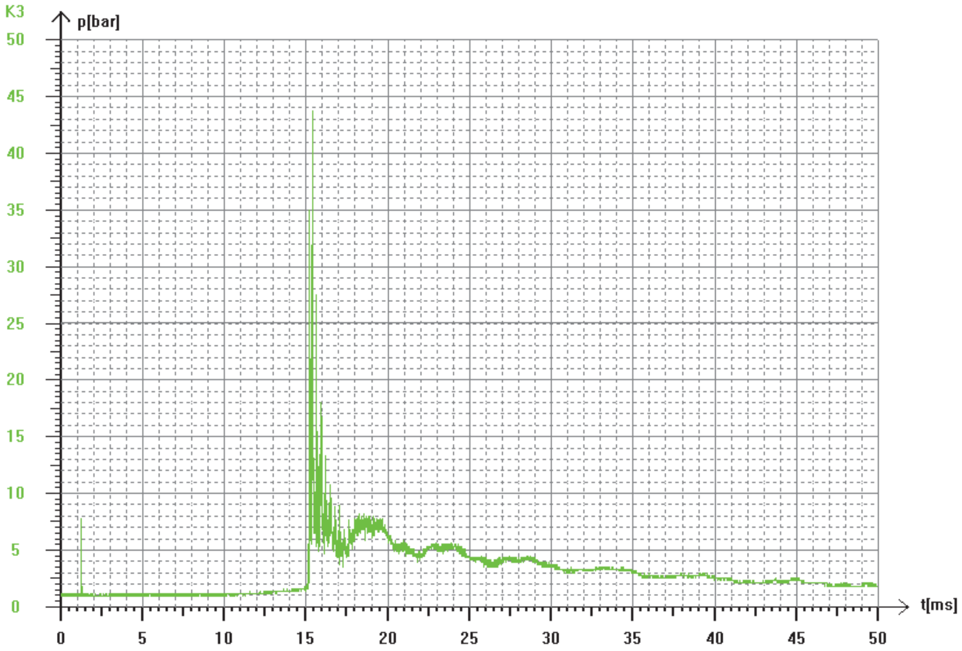

Fig. 3. Extremely high pressure recorded

The phenomenon of pressure pilling is of critical importance for flameproof enclosures as it is responsible for the high peak pressure values recorded in Ex d motor enclosures and has to be specifically addressed by motor manufacturers. Pressure pilling is defined as being the result of an ignition in a compartment or a subdivision of an enclosure, of a gas mixture precompressed, for example, due to a primary ignition in another compartment or subdivision (SR EN 60079-1, 2015).

However, there are other factors involved than just the pre-compression, this meaning that the pressure pilling phenomenon is the result of the combination of: (1) the precompression effect arising from the jet flow from the ignition vessel; (2) the turbulence induced by the fast flame propagation (jet ignition) in the secondary vessel; and (3) the vent flowing toward the ignition vessel, which mitigates the peak pressure (Munro, 2017).

Fig. 4 shows the process schematically: an ignition in the left-hand compartment pressurizes the gas/air mixture in the right-hand compartment which once ignited creates a higher pressure (Munro, 2017).

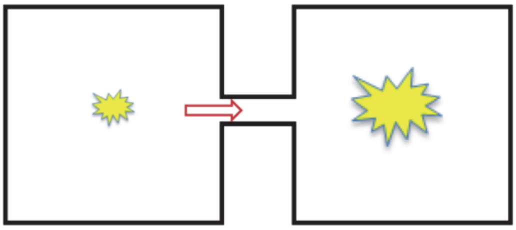

Fig. 4. Pressure pilling

Pressure pilling is of relevance to flameproof motors incorporating an air gap between the stator and rotor, because this can often provide the conditions necessary for pressure pilling to occur. Other communications paths can also arise, such as cooling ducts or open connections to the terminal box (Munro, 2017).

Having in mind that the maximum explosion pressures as a result of pressure pilling cannot be foreseen, the motor enclosure should be designed assuming that pressure pilling will occur and the manufacturer should have in mind the recommendations regarding the avoidance of this phenomenon, described in the following paragraphs (Magyari et al., 2012; Magyari, 2015, 2017).

b) Overpressure tests (SR EN 60079-1, 2015), which are carried out in our laboratory using the dynamic method. During these tests the ability of the motor enclosure to withstand 1.5 times the reference pressure recorded during the previous tests, is verified.

The tests in both a) and b) conditions are of paramount importance for the motor manufacturer, as he will have to design the motor enclosure in such a way as to withstand 1.5 times the reference pressure.

3. Results and discussions

After carrying out this research, the causes for the occurrence of high pressure peaks in the case of large electrical motor enclosures have been identified: (i) the extremely large internal volume (of hundreds and thousands of liters of explosive mixture), (ii) the geometrical shape of the motor enclosures, having in mind the latest tendency of motor manufacturers for the chemical and oil and gas industry to produce motors having ever more complex geometrical shapes, due to the cooling and mounting means, as well as (iii) the internal arrangement of these motors, which differ from the classical ones and from small frame size motors. The existence of several cooling fans, inside and outside of the large motor enclosures, as well as the cooling pipes designed to provide an efficient cooling of these motors with high and very high power, have been found to result in an extremely complex and complicated inner configuration, thus generating a different explosion behavior from the usual one, with much higher pressure peaks and smaller pressure rise times than normally envisaged (Magyari, 2017). So far it is unknown for sure the extent to which the geometrical shape, the internal arrangement, the location of the ignition source and its nature, the influence of the explosive testing mixture can be used in order to be able to predict when these pressure peaks are likely to occur and if so, what the resulting pressures will be.

The main causes for the occurrence of pressure peaks in the case of large rotating electrical machines have been found to be the following (Magyari et al., 2015; Magyari, 2017):

- the geometrical shape of the motor enclosure;
- precompression of the testing mixture (the internal arrangement / division of the motor enclosure);
- the type of gas used and the test mixture concentration;
- flame front acceleration and flame front instability.

a) Geometrical shape of the motor enclosure

This geometrical parameter plays an important role, especially if the ratio between the length of the enclosure and the cross-sectional dimensions is significant. In this case, when the burning is initiated from one end side of the motor, the flame front can be accelerated across the length of the enclosure, being capable even of making the transition from deflagration to detonation in certain extreme cases (Magyari, 2017).

As far as designing pressures are concerned, in this case we recommend that the ratio between the length of the enclosure and the smallest cross sectional dimension not to exceed the value of 4. For values of this ratio less than 4, the occurrence of pressure peaks is questionable, unless there are other factors which can generate it.

b) Precompression of the testing mixture (the internal arrangement/division of the motor enclosure)

The precompression of the testing mixture is one of the main causes for pressure peaks occurrence. These pressure peaks occur mostly in the smaller volume subdivision after the ignition took place in the higher volume subdivision. The small surfaces or the passages which connect the two subdivisions increase the likelihood of pressure peaks occurrence. If there are a series of subdivisions connected to each other, the explosion pressure will tend to increase as the flame front propagates from one subdivision to another, reaching the maximum value in the last subdivision (Magyari, 2015, 2017).

The phenomenon of precompression of the testing mixture occurs usually in the case of subdivided enclosures, such as is the case of motor enclosures or in the case of interconnected enclosures. The final values of the explosion pressures are a direct function of the testing mixture precompression, regardless of the causes which are responsible for the occurrence of the precompression of the testing mixture (Magyari, 2017).

As regards designing solutions, when subdivision (which is the case of motor enclosures, but not only) cannot be avoided, then the precompression (that takes place in the second subdivision, before the ignition of the testing mixture occurs), can be estimated as being the final explosion pressure in the first subdivision.

This approach is based on the following:

- there is no resistance in the flow of the explosive mixture between the first and the second compartment, during the burning of the explosive mixture in the first compartment;
- the burning in the second compartment occurs only after the complete burning of the explosive mixture in the first compartment;
- the initial pressure in the second compartment is equal to the final explosion pressure in the first compartment;
- the flow of the explosive mixture in the second compartment into the first compartment, during burning of the mixture in the second compartment, faces a high resistance.

c) Type of gas used and the explosive mixture concentration

Gases like hydrogen, acetylene and even ethylene (which can sometimes produce higher pressures than hydrogen when pressure pilling is an issue, due to its lower flame speed propagation), can produce higher explosion pressures and have a higher tendency to generate higher explosion peaks; also, a concentration which is near to the stoichiometric concentration is likely to result in much higher explosion pressures (Magyari, 2015). It is true though, that when pressure pilling occurs, slower flame speeds of non-stoichiometric mixtures can lead to higher pressures due to higher precompression before ignition in the second compartment.

d) Flame front acceleration and flame front instability

Flame front acceleration can be caused by several factors. These include the acceleration induced due to the mixture flow, the turbulence of the mixture and the flame front instability. The acceleration of the gas flow can occur at the openings and passages which connect the enclosure subdivisions. The flame front acceleration can also be produced by the turbulence generated by certain obstacles which add resistance in the mixture flow way or by the flame front instability due to acoustic resonance (usually associated with ventilation, during motor running) and due to normal differences existing at the interface of the burned and unburned mixture (Magyari, 2015).

The designer should reduce the likelihood of flame front acceleration, taking into account the indications concerning the design of subdivided enclosures and by minimizing the obstacles in the mixture flow path that can generate turbulence. The designer will not be able to eliminate the required apparatus inside the enclosure, and also to always eliminate the potential turbulence generators. The designer has to focus mainly on avoiding (where possible) enclosure subdivision by carefully arranging the inner apparatus. If the enclosure subdivision cannot be avoided, the designer has to eliminate the obstacles which are not necessary or the restrictions on the passages between different enclosure subdivisions (Magyari et al., 2011; Magyari, 2017).

Below we will present some experimental results obtained in the laboratory. The first two examples (Table 1 and Table 2, together with the corresponding Figs. 5 and 6) relate to two motors where no changes of the design have been operated by the manufacturer. This can lead to very high pressure peaks. The other two examples (Table 3 and Table 4 and the corresponding Figs. 7 and 8) refer to the changing of the motor design, this meaning an increased air gap between stator and rotor (from 1.5 mm to 3 mm) and an increased area of the aperture for the passage of winding conductors to the terminal plate. Tests have been carried out both with hydrogen and acetylene, but in Tables only the results representative, with acetylene have been shown.

Table 1. Very high pressures recorded, reference pressure test

No	*Ignition place*	*Precompression of test mixture [bar]*	*Gas*	*Percentage of gas in air*	*Temperature [°C]*	*P1 [bar]*	*P2 [bar]*	*P3 [bar]*
1	1	0.95	Acetylene	14.03	23.53	0.00	0.00	11.17
2	1	0.95	Acetylene	14.03	23.27	0.00	0.00	19.92
3	1	0.95	Acetylene	14.03	23.04	0.00	0.00	19.92
4	1	0.95	Acetylene	14.08	22.83	0.00	0.00	19.92
5	1	0.95	Acetylene	14.03	22.69	0.00	0.00	43.75

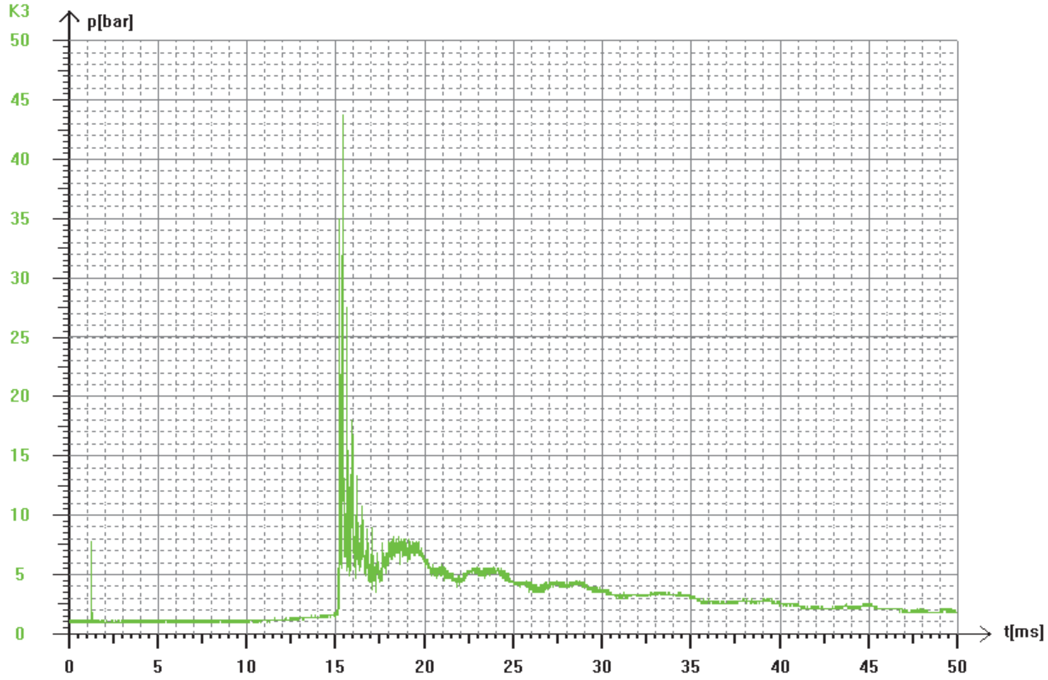

Fig. 5. Very high pressure measured under the terminal plate of the terminal box (acetylene)

Table 2. High pressures recorded during overpressure test

No	*Ignition place*	*Precompression of test mixture [bar]*	*Gas*	*Percentage of gas in air*	*Temperature [°C]*	*P1 [bar]*	*P2 [bar]*	*P3 [bar]*
1	1	1.50	Acetylene	14.03	20.21	16.99	8.98	40.04
2	1	1.50	Acetylene	13.98	20.22	10.74	24.02	9.18
3	1	1.50	Acetylene	14.03	20.24	18.36	8.98	39.06

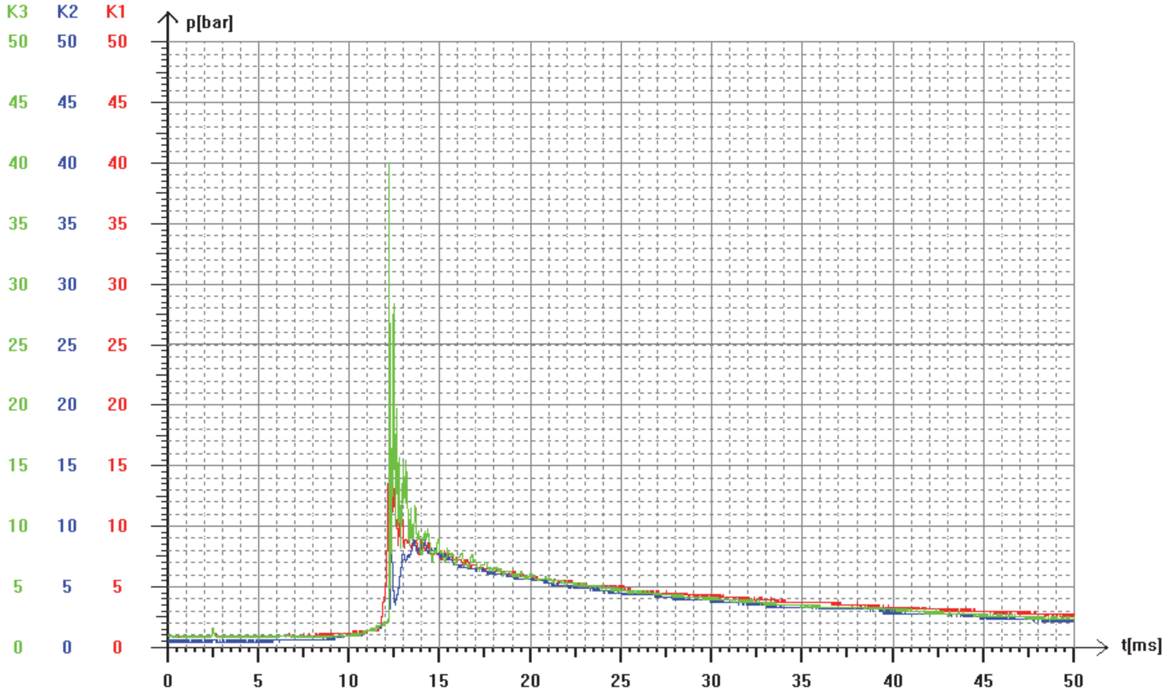

Fig. 6. Very high pressure recorded during the overpressure test (dynamic)

Table 3. Lower pressures recorded, reference pressure test

No	*Ignition place*	*Precompression of test mixture [bar]*	*Gas*	*Percentage of gas in air*	*Temperature [°C]*	*P1 [bar]*	*P2 [bar]*	*P3 [bar]*
1	2	0.93	Acetylene	14.08	19.47	8.59	5.16	6.72
2	3	0.93	Acetylene	13.94	19.44	5.51	5.47	3.87
3	2	0.93	Acetylene	14.12	19.42	9.96	4.92	7.34

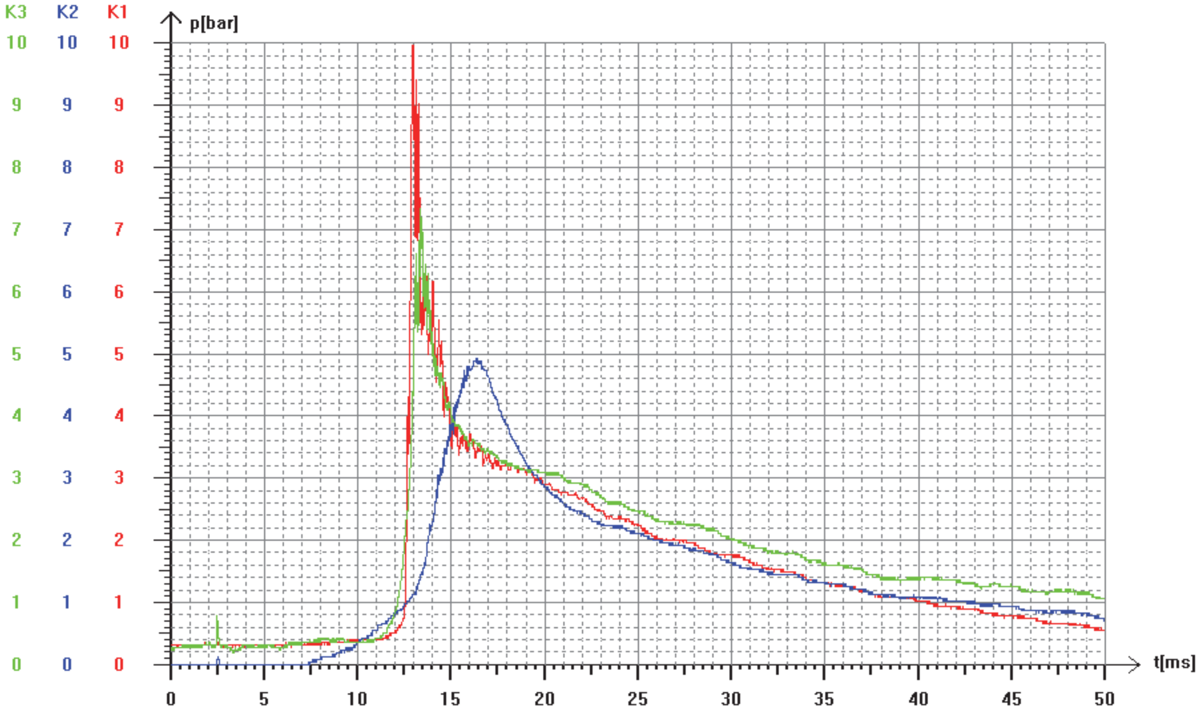

Fig. 7. Lower pressures – motor with increased air gap between stator and rotor

Table 4. Low pressures recorded, reference pressure test

No	*Ignition place*	*Precompression of test mixture[bar]*	*Gas*	*Percentage of gas in air*	*Temperature [°C]*	*P1 [bar]*	*P2 [bar]*	*P3 [bar]*
1	1	0.95	Acetylene	13.98	19.36	3.83	3.87	1.52
2	2	0.95	Acetylene	14.03	19.35	6.88	6.88	6.02
3	3	0.95	Acetylene	14.08	19.33	5.12	5.51	7.23
4	2	0.95	Acetylene	14.03	19.29	7.46	6.52	6.37
5	3	0.95	Acetylene	14.03	19.29	4.92	5.31	7.19

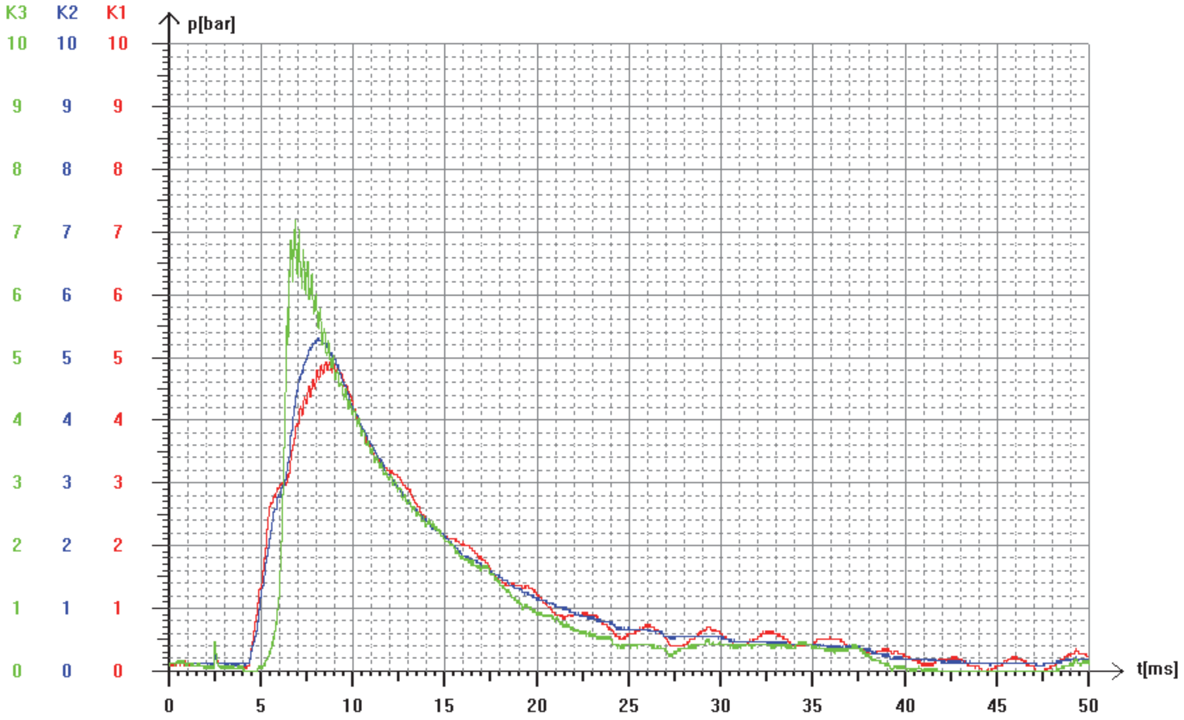

Fig. 8. Low pressures recorded in a motor

4. Conclusions

The research carried out in the specialized Flameproof Laboratory of INSEMEX has proven to be very useful in assisting designers of large flameproof electric motors to enhance the design of motors, so as to make them more reliable when testing in explosive mixtures.

Designing the motor enclosure, together with its internal arrangements could prevent pressure pilling, while it is often possible to reduce the explosion pressure due to pressure pilling, to an acceptable level. This can facilitate motor manufacturers to produce easier enclosures design with respect to the maximum pressures that can be developed.

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