# Diagnostics of Extinguishing Process in Low Voltage Devices by Pressure Field Measurement

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The article deals with the diagnostics of extinguishing process in low voltage devices by the means of pressure measurement in several points. The first part explains the technique of pressure measurement in switching devices and focuses on proper sensor properties and the problems of natural frequencies of the whole setup. The second part contains an example of pressure measurement analysis of the real device under real conditions, i.e. with the values of short-circuit currents in the range of tens of kA of prospective current with full voltage performed in the Laboratory of switching devices, Brno University of Technology. The last part compares the diagnostics method based on pressure measurement with other diagnostics techniques suitable for arc burning study under real conditions.

**Keywords:** pressure measurement, extinguishing process

## 1 INTRODUCTION

During opening of the mechanical switch under load or fault conditions, an electric arc is ignited between contacts. The whole process is finished after arc extinction, which may be, mainly for short-circuit conditions, very demanding.

The arc behavior can be mathematically described by the well-known magnetohydrodynamic equations, consisting from equations describing fluid flow (1-3) and equations describing electromagnetic field, which are Maxwell's equations.

$$\frac{\partial \rho}{\partial t} + \operatorname{div}(\rho \mathbf{v}) = 0 \quad (1)$$

$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \operatorname{div}(\rho \mathbf{v}\mathbf{v}) = \rho \mathbf{f}_{\mathrm{e}} + \nabla p + div\,\bar{\tau} \quad (2)$$

$$\frac{\partial (\rho H)}{\partial t} + \operatorname{div}(\rho H \mathbf{v}) = \operatorname{div}(k \nabla T) + \rho \mathbf{f}_e \cdot \mathbf{v} + q_H + \operatorname{div}(\bar{\tau} \cdot \mathbf{v}) + \frac{\partial p}{\partial t} \quad (3)$$

As follows from equation (2), the arc movement towards quenching chamber is mainly influenced by pressure field distribution (which in turn is connected with Joule heating) and by magnetic field creating electrodynamic forces acting on arc. Thus, the knowledge of pressure field distribution in real devices helps to understand arc behavior.

## 2 PRESSURE MEASUREMENT

To measure pressure during extinguishing process, one needs to be familiar with several phenomena and their proper treatment so that the measured values and pressure curves depict the correct situation.

In the following paragraphs, some of the important phenomena are explained with the help of experiments. The results of these experiments showed relative importance of these phenomena for proper curves reading.

### 2.1 REDUCTION OF SENSOR ACCELERATION

During extinguishing process, the electrodynamic forces may create acceleration of the whole tested device, which could be detected by piezoelectric pressure sensors. This could be partially avoided by proper device and sensor fixation, which is, however, sometimes difficult to fully fulfil – e.g. for somewhat flexible plastic parts of the device. The other thing is that some sensors are more vulnerable to detect device acceleration than others. The whole phenomenon mainly arises when relatively small pressures are to be measured.

This can be seen in Fig. 1. The pressure curve on the left side represents the pressure in the chamber, while on the right, when the arc is clearly extinguished, there is a "false" pressure coming from device and sensor vibrations. To avoid this, the device has to be fixed properly and other sensor more resistant against acceleration has to be used.

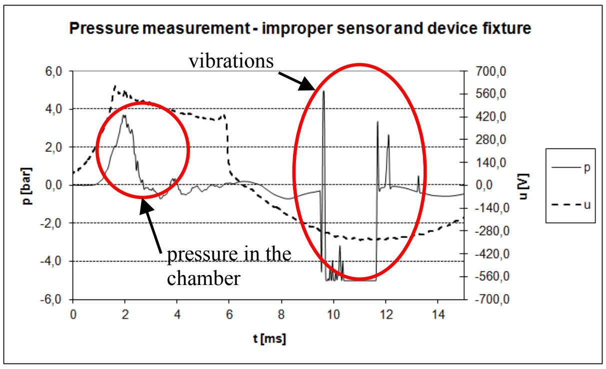


*Fig.1: Acceleration captured by pressure sensor*

## 2.2 RESONANT FREQUENCIES OF ADAPTER

To connect sensor to the point where the pressure is to be measured, it is necessary to use an adapter requiring only small diameter (typically M3-M5) so that there is only little influence on the aerodynamic conditions in the device under test. Typical configuration is presented in Fig. 2.

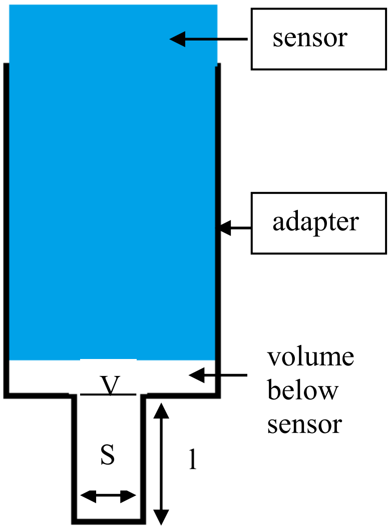


*Fig.2: Sensor and adapter creating Helmholz resonator*

The sensor and adapter create so call Helmholz resonator with natural resonant frequency of pressure oscillations. The resonant frequency is given by the following formula:

$$f_n = \frac{a}{2\pi}\sqrt{\frac{S}{V \cdot l}}, \qquad (4)$$

Where $a$ stands for the speed of sound in the given area, $V$ is the volume of the cavity, $S$ is the cross-section of the channel and $l$ is the length of the channel. The volume $V$ acts like a spring and the volume of the channel acts like a mass.

For practical measurement of the pressure during arc burning, it is necessary to distinguish between pressure change due to arc or air movement and “false” pressure change due to resonance in the adapter. The latter one has to be filtered-out by some means. The problems may occur when the oscillation frequency is near to the pressure changes in the chamber.

This can be seen in Fig. 3-5. Fig 3 shows the pressure curve without any filtering. The pressure oscillations are not caused by arc movement, but arise from resonance behavior of the adapter. Fig. 4 shows the same measurement, but the pressure curve is filtered-out. There are many suitable filters to do so. The most commonly used are low-pass filter (sometimes possible to be hardware implemented) and moving average. The latter one was used in Fig. 4 with 15 samples to be averaged every time. This phenomenon can’t be simply avoided by lower sampling frequency.

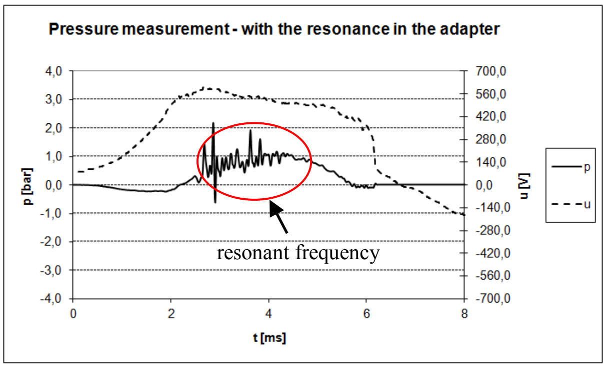


*Fig.3: Pressure measurement with adapter resonant frequency*

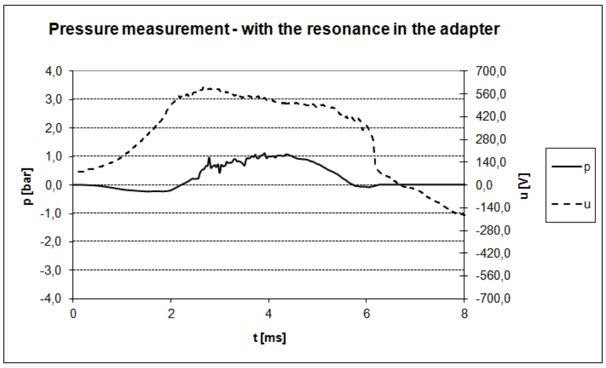


*Fig.4: Pressure measurement with filtered-out adapter resonant frequency*

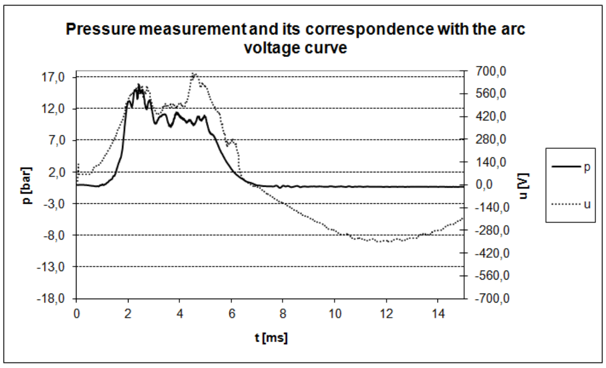


*Fig.5: Pressure measurement with filtered-out adapter resonant frequency*

However, when the filters are being used, it is necessary to be conscious about pressure changes in the chamber due to arc (air) movement. These have not to be filtered out! An example is shown in Fig. 5. There is an evidence that the pressure changes somewhat correspond to the arc voltage changes and are not given by adapter resonant frequency.

### 2.3 THERMAL SHOCKS TO THE PRESSURE SENSOR

Since the arc plasma has very high temperature, the thermal shock to pressure sensors occurs when they are not properly protected. This phenomenon usually leads to pressure decrease to unphysical negative values. Fig. 6 compares the pressure measurements with and without protection against thermal shock.

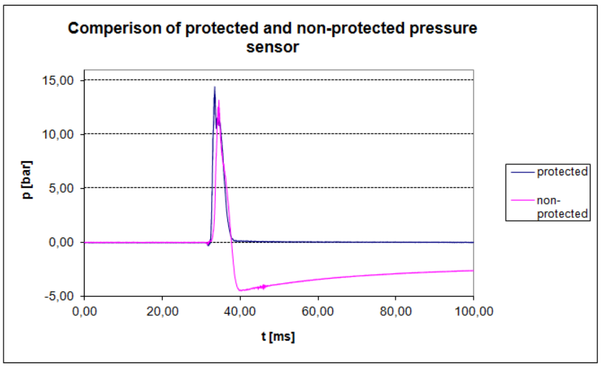


*Fig.6: Pressure measurement with and without protection of the pressure sensor*

To protect the pressure sensor, two important things have to be taken into account - the protective "grease" composition and the thickness of the protective layer. Most suitable materials are based on silicon grease. Also the more viscous greases can be used, but here, the thickness is of high importance.

## 3 EVALUATION OF PRESSURE CONDITIONS UNDER REAL CONDITIONS

The following examples (Fig. 7 and 8) show the pressure evaluation taken under real conditions – prospective currents in the range of tens of kA and test voltage 440 V.

Fig. 7 shows the example of device failure (low-voltage circuit breaker) which was simulated by change in quenching chamber. It is visible how the pressure corresponds with the current value. The peaks of the pressure are lacking for about 0,5-0,8 ms, because the pressure was measured outside the chamber. The aim was to verify the maximum pressures on plastics parts.

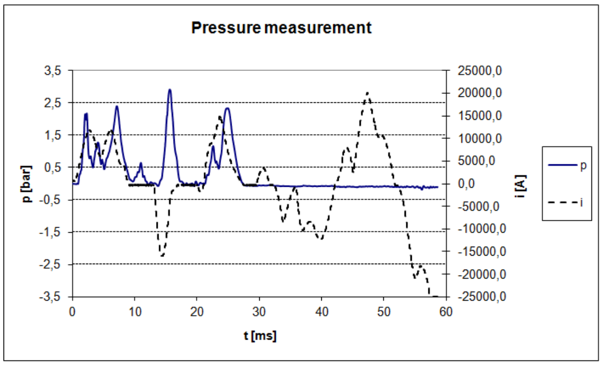


*Fig.7: Pressure measurement with simulated failure*

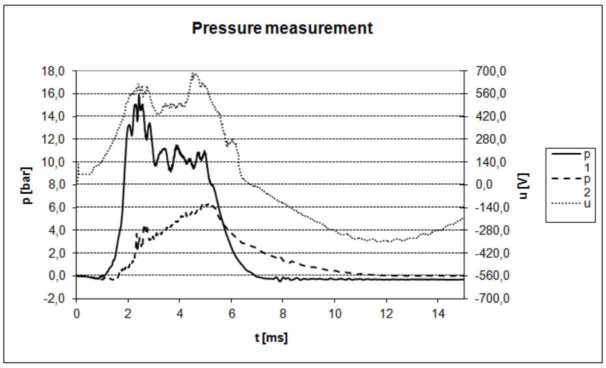


*Fig.8: Pressure measurement for arc behaviour estimation*

Fig. 8 shows two different points where the pressure was measured – in front of the chamber (p1) and behind the chamber (p2) of low-voltage circuit breaker. The peak values influence the required strength of the construction parts. The simultaneous oscillations after 2ms show the movement of the arc in the chamber – from the derivative of the pressure curves, it is clear that the arc travels in the chamber forward and backward, however, the voltage shows no arc reflection from the chamber at the beginning.

## 4 SUMMARY

There are many methods for arc diagnostics in low-voltage devices. The advantage of pressure measurement is that it requires no opening of the device under test (the small holes are filled with sensor adapters) provided that the required strength of the parts is not adversely affected, or usage of transparent covers (optical diagnostics), which may affect gas dynamics.

However, it is necessary to treat several phenomena mentioned above to get reliable results.

From the pressure curves, it is possible to get not only maximal values necessary for strength of plastics parts, but it is possible to estimate gas movement and potential problems in quenching chamber aerodynamic conditions. The pressure measurement may also serves as a method for validation of CFD models of electric arc.

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