APPLICATION OF ACOUSTIC EMISSION IN OPTIMIZING THE DESIGN OF NEW GENERATION CASTINGS OF HIGH-VOLTAGE ELECTRIC DEVICES

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Abstract

The technological progress in power systems requires the application of new solutions that will meet higher specifications than the currently used, in all parts of equipment design. This also refers to the external castings of power devices, especially those operating over a long time under high-pressure SF\(_6\) dielectric gas. Increased requirements include a 20% increase of the SF\(_6\) operating pressure and the same increase of the destructive test pressure, and simultaneous reduction of the casting weight. In this paper we present test results of casting materials and strength calculations for the implemented changes in design. The optimization and design verification activities included acoustic emission (AE) measurements performed during a hydraulic pressure test. The results obtained allowed to determine the locations and pressure values, at which the plastic strain began to occur, and the position of the final failure.

Introduction

Technological progress in power engineering has been observed over recent years and requires the implementation of solutions meeting higher requirements than those used at present in all devices and elements in this area, taking into account also the external castings of these devices, which are operated under multi-year influence of high-pressure SF\(_6\) gas as the best available dielectric. Higher requirements consist in 20% increases in working, control and destructive SF\(_6\) pressures, as well as the reduced weight of castings [1]. Increased requirements in relation to castings can be met through the implementation of structural modifications and new manufacturing processes, with simultaneous increase in their strength and tightness adapted to higher pressure. Users of the castings demand also the delivery by manufacturers in ready-to-assemble commercial condition, i.e. as fully machined castings accompanied with the certificate confirming their strength, gas tightness matched to higher pressure, gas permeability checked with helium and resistance to control and destroying pressure checked in hydraulic test. Correct functioning of such castings requires appropriate strength and gas tightness to keep required working pressure of filling medium for 30 years. An example of such a casting is shown in Fig. 1.

To meet such rigorous requirements, a series of examinations was carried out during structural and manufacturing-process optimization, including examination of microstructure, material properties, modeling process and behavior in working conditions [2]. Hydraulic pressure tests with simultaneous recording of AE signals on the basis of the accepted criteria were some of the significant examinations during optimization and checking of the finished products. The AE examination was carried out during increasing and maintaining the pressure until the part was...
destroyed. Vallen Systeme AMSY-5 multi-channel signal recording system with R2007.0904 software was used for AE examination. Because of non-magnetic properties of the cast material, the sensors were attached with assembly tapes. Figure 2 shows the arrangement of the sensors on the casting [3]. The examination was aimed at correlating AE results with test pressure value, and also at locating the source locations, where because of the complex shape of the element the crack could develop the earliest.

![Image](image1.png)

**Fig. 1.** Example of an aluminum casting, an element of high-voltage electric device.

![Image](image2.png)

**Fig. 2.** Example of sensor arrangement on examined T-connection.

**Results**

Figure 3 shows AE signal amplitude vs. time, and reflects the increasing AE activity with pressure during a pressure test [4, 5]. The locations, at which the AE signal sources occur initially, are the local stress concentrations resulting from the cast geometry. The pressure applied during examination was much higher than the working pressure of 3 bar. The maximum pressure achieved during examination was 38 bar. Thanks to holding the pressure at various levels, the occurrence of Felicity effect was revealed, determining the level of structural damage, at the pressure amounting to 25 bar for one of these casts.
Example of such an effect can be seen on Fig. 3, where the first occurrence of Felicity effect is marked. A large number of the AE counts can be seen within area 2 as compared to area 1. Although the AE signals from both groups were recorded during the same pressure-hold level of 25 bar, higher AE intensity (higher number of counts of higher amplitude, energy or longer duration) and activity (higher number of hits, counts and signals of higher energy) during the second pressure hold at the same level shows the existence of significant structural damage. This example indicates the occurrence of Felicity effect, which determines the presence of localized plastic deformation.

Subsequent analysis fully confirmed the occurrence of the Felicity effect (Fig. 4). Already at 25 bar, significant structural damages were found in the material, determining its possible use.

Fig. 3. Amplitudes of the AE signals recorded during the time when the pressure was held during the pressure test performed on a T-connection casting, including the pressure change pattern and the Felicity effect analysis.

Other parameters used to evaluate the damages presented in this article are RA value and the mean frequency for an AE hit, Fa, defined in JCMS-III B5706 [6]. The RA value is the ratio of rise time to amplitude, expressed in ms/V [7]. The Fa value is the ratio of AE counts to the duration. By using these two indices we can determine whether the nature of a crack is a result of tensile or shear forces. Ohtsu and coworkers [8] linked the Fa vs. RA relation to the tensile/shear nature of concrete cracks, but recently Takuma [9] used these indices successfully to evaluate the degree of tool wear, which demonstrates that these parameters can be successfully used for other applications [10].
Fig. 4. The pressure during the pressure test performed on a T-connection vs. the AE counts, showing the Felicity effect. Insert shows the start of AE activity at 21 bar (Felicity ratio of 0.84).

Fig. 5. Relations of Fa frequency indexes and RA values.

In connection with the above, the next analysis was aimed at comparing the relations of the Fa mean frequency and RA values. The relation between these indices is shown in Fig. 5. There
are two areas isolated in the figure. The first area, B1, is characterized by high Fa frequency values, and low RA values. The other, B2, presents low Fa values, and RA values are higher than in B1 area.

Fig. 6. Total changes of AE signal amplitudes recorded during pressure hold-ups in the course of the pressure test of the tee.

We can assume that the AE signals coming from the cracks have high amplitudes at very low rise time values. B1 area isolated in Fig. 5 is distinguished by such AE signals. While the AE signals that come from crack friction show low amplitude with high values of the rise time. The signals of such parameters are grouped in B2 area.

Figure 6 presents the total AE signal amplitude changes recorded during pressure changes in the course of the pressure test of the tee. The signals of B1 area, resulting from the cracks and featuring high Fa frequency value and low RA value, marked in Fig. 6 by a green line, are the dominant signals during all the pressure holds. B2 signals, coming from the crack friction and featuring low Fa values and higher than B1 area RA values, marked in Fig. 6 by a red line, are not recorded as intensively as the crack signals, and appear in the early part of the pressure hold stages. It is worth noting the sudden rise of B1-type signals (from the cracks) after exceeding the pressure of 30 bar. Note that typically this rise occurs mainly at a fixed pressure at the level of 35 bar. Figure 7a presents localized events recorded in one of the cast areas with a crack drawn (in red). Compare with the crack visible on Fig. 7b. The localized AE events occurred along the crack.

It is noteworthy that the location, at which the plastic deformation was located, and at which the final crack occurred, is only a one of a few locations where stresses determined with the finite elements method [11] are concentrated (Fig. 8). Use of the AE monitoring allowed us to verify the numerical calculations based on assumption of uniform cast material and ideal mapping of the assumed shape.
Fig. 7 a) Planar location of the AE events recorded during the entire pressure test of a T-connection in the area of 1, 2, 7 and 8 sensors; b) Picture of the T-connection with attached sensors and a clearly visible crack at center.

Fig. 8. Reduced stresses at 20-bar pressure with indicated positions of concentrated stresses.

Other examination results, presented on Figs. 9 and 10, show the change of amplitude, signal duration and AE counts for various test pressure ranges. The ranges 5-10 bar, 10-15 bar and 25-30 bar were selected for the presentation. It can be seen that, in initial testing phase within the 5-10 bar range, the recorded signals were of low amplitude, no higher than 50 dB. Analysis of their character showed that they are caused by plastic deformation. Because the source of the signals was not found, plastic deformation in this pressure range was assumed in a significant part of the cast material. An analysis of the AE signals occurring in the subsequent pressure range of 10-15 bar shows a distinct increase of amplitude of the recorded signals. We also observed distinct
localization of signal sources, which in most cases were located at the central part of the casting, at the place where the cracking occurred in the final phase of the test. The last results in the 25-30 bar range (the cracking occurred at 31 bar) showed the further growth of both the signal amplitude and the number of located sources. The amplitude distribution within the 25–30 bar area, as shown in the Figure 10, reveals very high amplitude signals at the level of 100dB, which obviously proves propagation of the crack.

Fig. 9. Signal duration vs. amplitude. Green: 5-10 bar; Red: 10-15 bar; Blue: 25-30 bar.

It has to be noted that just before the cracking, at the 28-31 bar range, a relatively small number of AE signals were recorded. This low AE activity probably results from the relatively low ductility of the material. Along with the pressure rise, resulting from plastic deformation of the material, there is a decrease in the number of mobile dislocations whose movement is the source of the AE signals. Figure 10 also allows one to observe simultaneous rise of the mean amplitude of the AE signals with the rise of the pressure value. In addition, the rise of AE signal amplitude ranges can also be observed.

Conclusions

The presented results show that the AE method can be an efficient tool for optimization of structure and the manufacturing methods of pressure devices. Using the AE measurements during the pressure tests allowed us to determine the particularly strenuous spots and the beginning of plastic deformation in the examined castings. Knowledge of locations and pressure ranges, at which the plastic deformation was initiated allowing us to implement the structural changes aimed at decreasing the stress concentration. No phenomenon of plastic deformation localization was found after optimization was performed. This is significant for achieving the long-term operation without a failure.
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