THRESHOLD INDEPENDENT ACOUSTIC EMISSION MONITORING OF A CRIMPING PROCESS IN SERIES PRODUCTION

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Abstract

End fittings of high-voltage insulators are connected to a fiber-reinforced rod by a crimping process. Depending on the process parameters, pressure and duration and some arbitrary parameters of the fitting and the rod, it might happen that the rod becomes damaged during the crimping process. A feasibility study showed that a damaging and a non-damaging crimping process can be distinguished by a factor of 100 to 1000 of the acoustic emission (AE) energy rate picked up by an AE sensor mounted on a crimping claw. Requirements for AE equipment suited to monitor series production of high-voltage insulators are identified. The realization of a rugged monitoring device is described.

Keywords: High-voltage insulators, high-voltage isolators, crimping monitoring, FRP, end fitting

Application

Figure 1 shows the crimping of an end fitting onto an FRP rod using a hydraulic press. Figure 2 shows two different types of end fitting already pressed to the FRP rod. Figure 3 shows a part of a completed high-voltage insulator.

Fig. 1 Crimping an end-fitting onto a rod.

Fig. 2 After crimping.

Fig. 3 Final product.

Such insulators may carry heavy high-voltage lines: they have to bear the weight and maintain electric isolation.

The end fitting to FRP rod joint needs to be very reliable. Failure of this joint may cause the high-voltage line to sag or even to fall down. This could cause injury or even death to humans and harm the environment. Further, the operation of the high-voltage line would be affected and/or interrupted.

If the crimping pressure is too high, the FRP rod inside the end fitting is damaged. This will cause failure of the FRP rod below the nominal tensile load. If the crimping pressure is too low, the FRP rod is pulled out of the end fitting before reaching the nominal tensile load. Hence the crimping process needs to be optimized to reach a crimping pressure as high as possible, but must avoid a damaging over-pressing. A fundamental analysis of this topic can be found in [1, 2]. Both studies use AE measured during pull-out tests to verify theoretical analysis and numerical simulations.

High-voltage insulators are usually tested (by manufacturer and buyer) by destructive pull-out tests of random samples. This reduces the risk of using damaged FRP rods, but the risk still remains. Obviously, there is a need for monitoring the crimping process to identify ‘problematic’ joints or inadvertent changes of process parameters. Further, it could be used to determine the optimum values for crimping pressure and crimping duration. We found a first publication of an online-monitoring of the crimping process using AE in 2001 [3]. The authors suggested to evaluate the time evolution of the hit rate.

Realizing the Online Monitoring of the Crimping Process

1. Feasibility Study

In 2001 we made a first feasibility study, which came to the following results:

- In the frequency range 300-700 kHz we obtained a better signal-to-noise ratio than in 100-300 kHz („noise“ includes undesired background signals).
- The sensor can be mounted on the fix crimp claw. The energy transfer from the FRP rod into the claw is reproducible and sufficient for testing (see Fig. 4).
- A 40 dB threshold provides enough sensitivity
- Noise signals can be neglected. This was shown e.g. by crimping an end fitting to a steel rod where no damage can be introduced by over-pressing. Over-pressing causes a rise of the AE energy rate by factor of 10-1000.

Fig. 4 Sensor bonded to the fixed crimping claw.

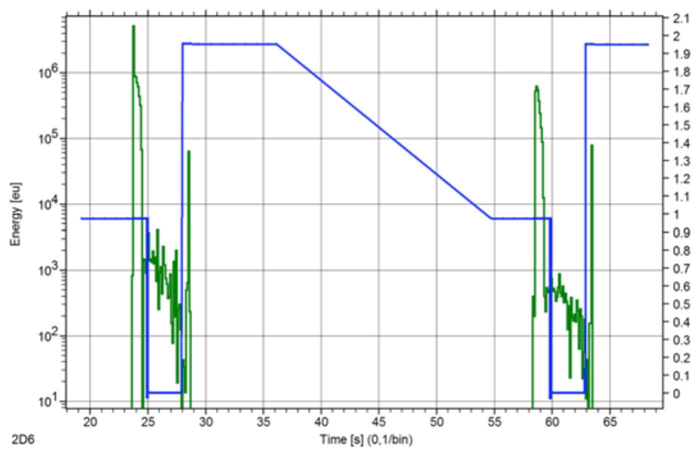

Fig. 5 Energy rate during steel-rod-crimping.

Figure 5 and 6 show data of the first feasibility study. Figure 5 shows in green the energy rate (left axis) per 0.1 s vs. time for two crimping processes on a steel rod. The blue line (right axis) shows the processes steps: Value = 1: Closing claws (e.g. 19-25s); Value = 0: Pressure increase and hold (e.g. 25-28s); Value = 2: Pressure release and opening the claws (e.g. 28s).

This test allows us to rate the AE caused by the hydraulic press itself, because no FRP could contribute to the measured AE. One can see a brief increase in the energy rate where the crimping starts and ends. This can be explained by the touching and lift-off of the crimping claws.

Figure 6 shows initially (starting at 175s) the crimping of an FRP rod with an extend pressure-hold period causing a damage to the rod. From 183s the energy rate increases by a factor of 100-1000, indicating damage. From 228s, ‘good’ crimping started next where the energy rate is comparable with the steel rod crimping. Figure 6 provides an additional, important hint: while damaging the FRP rod (from 183-189s), the energy rate decreased only few times, but the hit rate (not shown) fluctuates very strongly. This means: for this application, the hit rate is less distinctive than the energy rate. For an industrial device, this raises the requirement for a threshold independent measurement of an amplitude or energy parameter.

AE equipment used for this feasibility study: sensor VS900-M, sensor cable SEC (1.2 m), preamplifier AEP4 (34 dB), AE signal processor ASIPP with filter 300-850 kHz, threshold 40 dB, DDT: 0.4 ms, RAT: 1.6 ms, AE-System: AMSY4 (Vallen-Systeme GmbH).

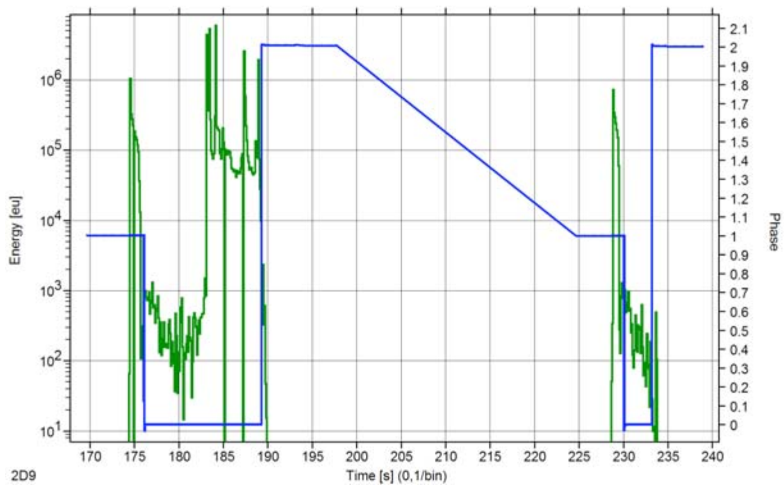

Fig. 6 Energy rate for a damaging (left) and a good crimping of an FRP rod.

2. Demands on a device for monitoring a series production

- Installation and operation of the device needs to be very simple and straightforward. Series production is done by trained workers where the time for instructing frequently changing staff is very limited. AE know-how cannot be expected and time-consuming operation won't be accepted at all.
- Maintaining the inspection equipment, *AE device* must not be more complicated than a simple voltmeter.
- Directly after crimping, the AE device needs to visually and acoustically indicate one of three possible results: a) good crimping; b) questionable crimping; c) damaging crimping.
- Nothing more than noticing the results shall be required from the crimping staff. Hence the AE device needs to detect start and end of the crimping process itself, e.g. from the crimping pressure, and to evaluate the data accordingly.
- Correct operation of the AE device needs to be easily verified.
- The AE device needs to be rugged and connectors must differ from each other to avoid wrong connection.
- The AE device needs to determine at least one energy or amplitude parameter without the need for setting a threshold (threshold independent).

These demands show clearly that an AE system developed for well-trained AE service providers and researchers cannot be the best solution. Meeting these demands requires a different concept.

3. Market Situation

Between 2001 and 2006, we received about 10 inquiries for a turn-key AE device to monitor crimping of end fittings to FRP rods. This did not justify a market research or a self-funded development of such AE device. At the beginning of 2006, Pfisterer Sefag AG indicated their interest in a cooperative development of such a device. At this time, a prototype of the ASCO-DAQ1 existed and the effort to adapt this to the requirements was manageable and justified.

4. ASCO-DAQ2 for Monitoring the Crimping Process

ASCO-DAQ2 is a combination of AE signal conditioner ASCO-P (for this application the derivative ASCO-PH3, 300-750 kHz) and the 4-channel USB data acquisition module DAQ2. Both modules are integrated in a small, rugged case connected to the PC via a USB cable. Windows 2000 or XP is recommended as PC operating system.

Fig. 7 ASCO-DAQ mounted to hydraulic press.

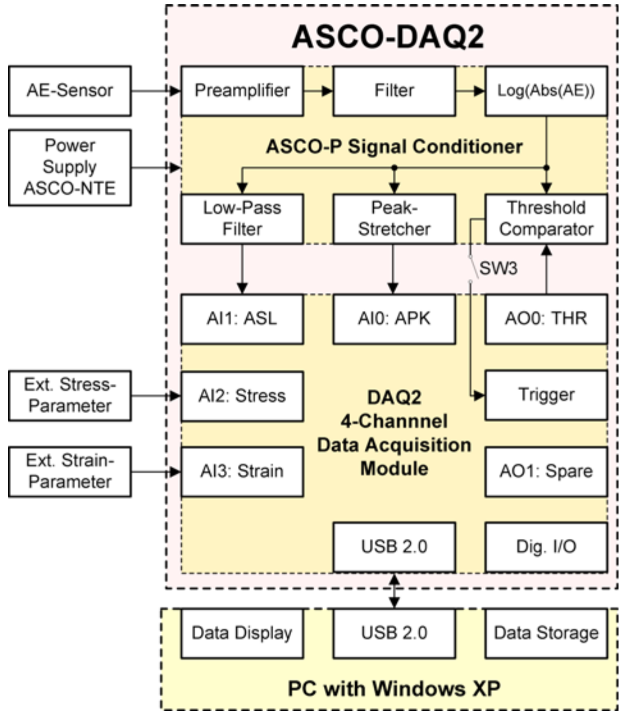

Fig. 8 ASCO-DAQ2 hardware schematic.

ASCO-P amplifies and filters the AE-signal from the AE sensor and determines the logarithm of the absolute value. This logarithmic signal is scaled to 40 mV/dB$_{AE}$ and then passed to the peak stretcher and the low-pass filter. The low-pass filter averages the signal and provides it as ASL (average signal level). The peak stretcher elongates shortest peak amplitudes to approximately 50-ms duration. With this, even a 40-ms sampling interval (25 Hz) is sufficient to detect shortest peak amplitudes as APK (amplitude peak) signal. The signals ASL, APK and the crimping pressure are recorded by the data acquisition system at 10-ms interval (100 Hz).

5. Examples

Figure 9 shows an example for a good crimping. The colors indicate:

- Brown: pressure (right axis, in bar),
- Blue: ASL Signal (left axis, in dB$_{AE}$)
- Green: APK Signal (left axis, in dB$_{AE}$)
- Yellow: limit for *Warning*
- Red: limit for *Bad*

The limit lines are bi-colored: the first color indicates if the limit is for *Warning* (yellow) or *Alarm* (red); the second color indicates whether the limit is for the signal ASL (blue) or APK (green). ASL stayed below 42 dB$_{AE}$, and APK below 73 dB$_{AE}$. The peak of 71 dB at 6.5 s was verified to be meaningless.

Figure 10 shows an example for a bad crimping: ASL exceeded 85 dB$_{AE}$, APK was even above 103 dB$_{AE}$. (measurement range is up to 106 dB$_{AE}$). The electronic noise can be seen at the very left, before the pressure increase. It is about 23 dB_{AE} for ASL and 33 dB_{AE} for APK.

If only the *warning limit* but not the *bad limit* is exceeded, a yellow *warning* field is shown instead of the red *bad* field. The text in these fields can be defined by the user. Simultaneously with showing the *green/yellow/red* field, one of 3 wav files can be played for the acoustic indication.

Fig. 9 An example for a good crimping screen.

Fig. 10 A screen after a damaging crimping.

6. Control by Pressure

Only at the first start-up, the settings (e.g., limit and texts to be shown) need to be defined. For practical use, one needs to start the software and switch the acquisition mode on. Data evaluation starts as soon as the pressure exceeds a certain value and data evaluation ends when pressure falls below a certain value. After data evaluation is completed, the result is shown graphically and indicated acoustically. The operator needs not to care about the AE device: he starts the crimping process as before and waits until crimping is completed. He just needs instructions how to proceed in case of questionable or bad crimpings.

Pressure control can be deactivated to allow for manual operation of the AE device. Further details; e.g., how data is stored, post-test analysis possibilities and more can be found in [4].

Conclusion

An AE device to monitor series production of crimping end fittings onto FRP rods of high-voltage insulators was developed. Detecting over-pressing, which would cause catastrophic failure of the part, is reliable. The AE device is threshold independent and does not require intervention from the hydraulic-press operator as the crimping pressure controls data analysis. The result (good/questionable/bad) is indicated visually and acoustically immediately after crimping. The good cooperation between manufacturer of the high-voltage insulators and manufacturer of the AE device was important for the success of the project. Since the beginning of 2007, the AE device monitors the crimping in series production and prevents further processing of pre-damaged high-voltage insulators.

Potential for improvements

Fan et al. [3] suggested to also detect under-pressing (too low a crimping pressure) using AE. Whether this can be realized could be estimated if data from a sufficient number of good and under-pressed crimpings would be collected.

Discrimination between good and damaging crimping could be improved by numerical inversion of the analogue logarithm, subtracting a base line (background noise), and integrating the positive remainder. This was not implemented in order to keep the mode of operation, especially the setting of the limits, as simple as possible. An additional parameter *base line* would have increased complexity.

References

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