A New "Duration-Adapted TR" Waveform Capture Method Eliminates Severe Limitations

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Abstract. We implemented the world's first acoustic emission (AE) transient recorder (TR) module for a commercially available AE system (AMS3) already in 1992. The purpose was to store the waveform of the beginning of an AE burst with N samples before a trigger event, usually the first threshold crossing of a burst, and M samples in total, N, M, and sampling frequency were user-selected. M divided by the sampling frequency defined the duration of the stored waveform.

This is still the principle function of today's transient recorders, so we call it hereafter "Traditional TR data capture". It exhibits severe limitations for AE, mainly due to the concept of constant record length:

- for long duration bursts, record length is too short. Only the beginning of the burst signal can be seen.

- for short duration bursts, record length is too long. This wastes storage space and transfer volume,

- Increasing the record length increases the probability that more than one burst arrive in one burst signal waveform record. This makes automatic data analysis difficult.

The abovementioned limitations have recently been solved by implementing the new "Duration-adapted TR" waveform capture method. This method adjusts the waveform record length of each burst signal according to the measured duration, plus a user-defined number of pre-trigger- and post-duration-samples.

The data stream from ADC is continuously written to a controlled sequence of memory segments. Waveform data is read out of the memory, when feature data of a burst signal (hit data) is available and has passed a front-end filter. The memory address of the waveform data of interest (trigger moment) can be derived from the arrival time of the hit, and the number of samples to be transferred from the measured duration.

At proper settings of the parameters pre-trigger time, post-duration time, and duration discrimination time, the full waveforms of all hits will be captured and no waveform data can go lost, even when bursts overlap, as long as there is free memory available. Each hit would have one TR-record assigned.

A hardware trigger line is not longer needed for waveform capture. Hence, pool trigger works with pool channels in different chassis. In future, multiple pools of channels might be arranged for even more flexible pool trigger options.

A firmware upgrade adds this new functionality to all ASIP-2 signal processors delivered since 2007.

1 Introduction

Traditional transient recorders (TR) store the waveform of a hit. The term "hit" is used for an AE burst that triggered a feature extraction process by at least one threshold crossing. The length of the TR record, also called waveform record, is user selectable and independent of the duration of the hit. This is appropriate for applications, where a user is only interested in the waveform of the beginning of a burst. Only the beginning of a burst signal shows wave components that arrived directly from the source and is free from reflections. For a traditional transient recorder, a waveform example as shown in Figure 1 fulfils the expectations.

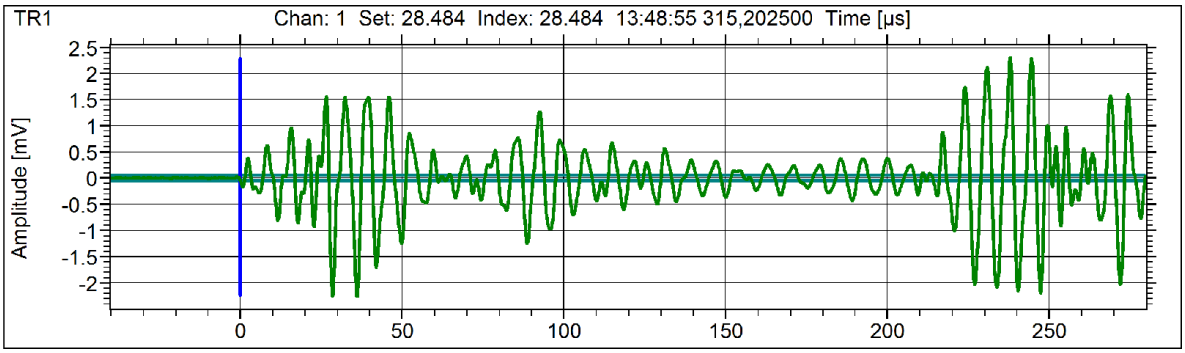

Figure 1. Waveform composed of 40 µs pre-trigger- and 280 µs post-trigger-time

The waveform in Figure 1 shows an early peak at about 25 µs after the first threshold crossing at t=0, a first reflection at t=90 µs and a higher peak at about t=240 µs. If the information in Figure 1 satisfies the user, then traditional TR data capture is still sufficient. If the hit data of the waveform in Figure 1 reports R (rise time) = 640 µs, then it is obvious, that the waveform data of the highest peak amplitude in the burst signal is not available, because the shown waveform ends at t=280 µs. If one acquires AE waveform data, in most cases the waveform around the maximum peak amplitude is of interest, too.

2 Terminology used for "burst", "burst signal", "hit", "hit data"

In Europe, AE terminology is defined by EN1330-9 [1] and this publication tries to adhere to it. The following shall clarify the used terminology in more detail.

"**Burst**" is used for a wave packet containing one or more peak amplitudes. It may overlay background noise or continuous AE. Each of Figures 2, 3 and 6 shows multiple bursts overlaid on the shown waveforms.

"**Burst signal**" is used for a waveform composed of a pre-trigger time, a duration (the time from first to last threshold crossing) and a post duration time. In most cases, the term "hit" could be replaced by the term "burst signal" and vice versa.

"**Hit**" is used for a burst that triggered feature extraction by at least one threshold crossing.

"**Hit data**" is used for the extracted features of a hit: Arrival time, Peak amplitude, Rise time, Duration, Energy, Signal Strength, Ring down counts and more.

3 Limitations of traditional TR recording for AE

For many research applications, users prefer to have waveform information about the full duration of a hit, especially, if the burst signal is composed of multiple peak amplitudes.

Figure 2 shows a longer time period of the waveform in Figure 1. Figure 1 shows only the part t = -40 µs to 280 µs.

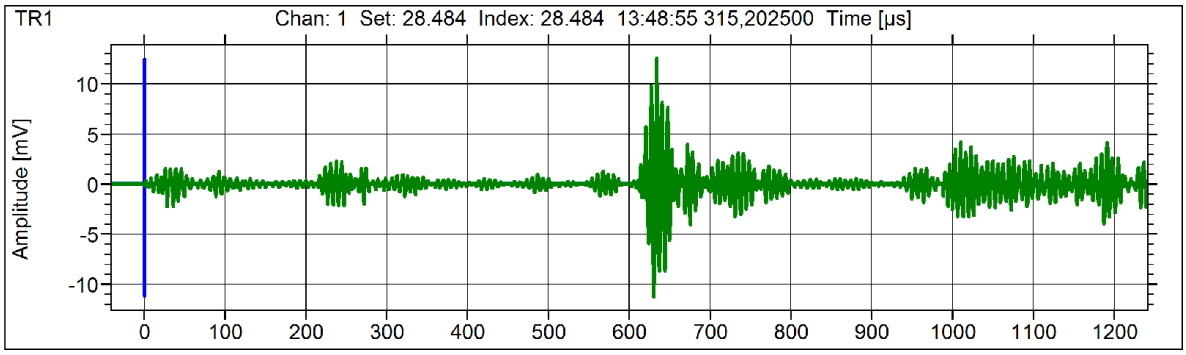

Figure 2. Same burst signal as shown in Figure 1 but over a longer time period.

Figure 3 shows the same burst signal over its full duration of about 3370 µs. The feature "signal duration" is defined as the time period from first to last threshold crossing. The first threshold crossing occurred at t=0, the last at about 3370 µs. Multiple short bursts overlay an increasing background level. The burst starting at t=2800 µs caused amplitude saturation of the measurement chain. Since there was no absence of threshold crossings between the bursts, the whole sequence of overlapping bursts composes per definition [1] one burst signal, and the hit data of this burst signal are: 94 dB peak amplitude, 3370 µs duration and 2800 µs rise time.

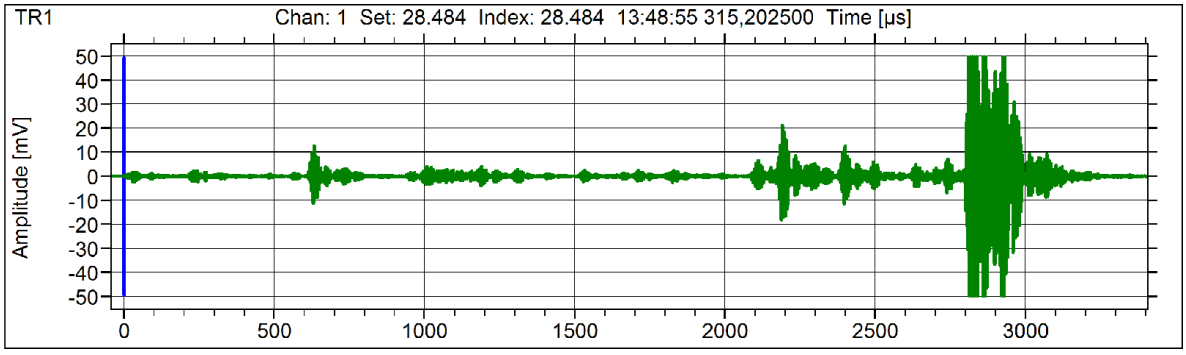

Figure 3. Same signal as shown in Fig. 1 and 2 over the full signal duration.

To see the signal in Figure 3 using a traditional transient recorder, a recording time of about 3400 µs would be needed. But this could cause the issue that more than one burst is recorded to one TR-record. See for example the waveform in Figure 4. Multiple burst signals in one TR-record makes automatic waveform analysis difficult and should be avoided.

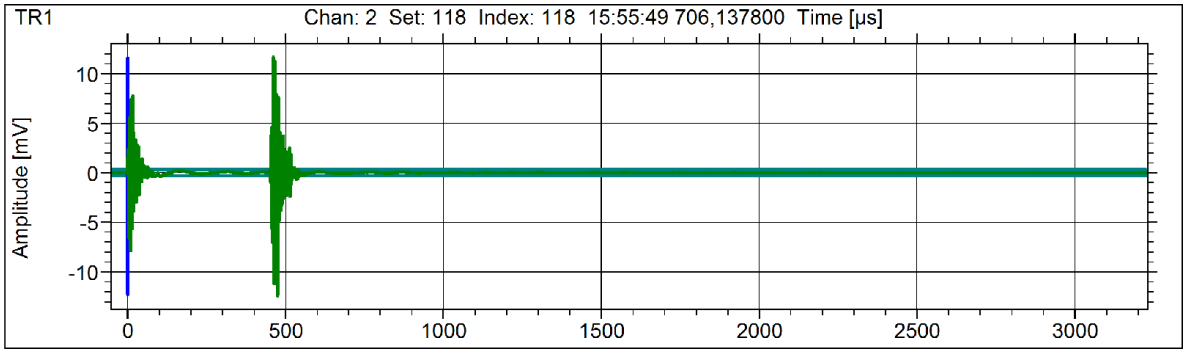

Figure 4. Undesired occurrence of two burst signals in one TR-record.

Back to the waveform in Figure 3: Since there was no absence of threshold crossings, a traditional transient recorder would have been triggered only once, at t=0 and would have shown only the first few 100 µs of the signal. For seeing the full signal duration, the user would have to use a continuous waveform streaming, with the disadvantage that this only works well for very few channels, that a lot of storage space and transfer volume is wasted and that searching for bursts of interest in an endless stream of data is not a trivial task. The streaming of waveform data can now be replaced by using the new waveform capture method.

Summary of the limitations of traditional TR for AE:

- For long bursts, only the beginning of the burst signal is recorded.
- Multiple bursts can occur in one TR-record.
- For a new hit, which arrives while the TR-record of the previous hit is not completed, or the defined no. of pre-trigger samples have not already been acquired, the TR record is not armed for a new trigger and TR data is not recorded for that hit.
- No waveform data is recorded for artificially started hits (after 104ms hit timeout).
- The pool trigger functions works only on pool-channels in same chassis.

4 "Duration adapted TR" waveform capture method

The "Duration adapted TR" waveform capture method overcomes the above described limitations.

As shown in Figure 5, a burst signal captured by this method is composed of three time sections: (a) the pre-trigger-time, selected by the user; (b) the signal duration, measured from first to last threshold crossing; (c) the post-duration time, selected by the user.

During pre-trigger time we see how fast the signal rises before the first threshold-crossing, during post duration time how fast it decays after the last threshold crossing.

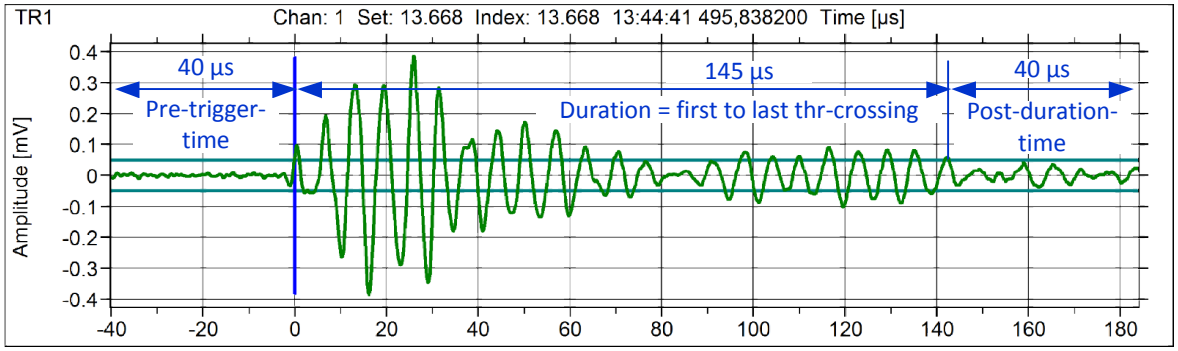

Figure 5. Waveform composed of 40 µs pre-trigger time, the time from first to last threshold crossing (=burst signal duration, measured by the feature extraction unit, here 145 µs), and 40 µs post-duration time.

The following behavior of the AE signal processor is not new but here explained in combination with the new waveform capture method: If at the end of a burst signal another threshold crossing occurs while the the duration discrimination time (user defined feature extraction parameter DDT) has not expired, the duration will become longer. In an extreme case, e.g. during the final phase of a destructive test, burst AE may change to continuous AE. In order to avoid self-blocking by a "never ending burst", the AE signal processor terminates the current hit process at 104 ms duration and starts artificially a new hit process, gaplessly. In this way, the AE signal processor masters bursts of extremely long

duration and even a transition of burst AE to continuous AE. Hit data of artificilly started burst signals are flagged by an A-flag and are specially treated by software: Their "artificial" arrival time is meaningless for location calculation, hence, those hits are not considered for source location. An example of the waveform of an artificially terminated hit is shown in Figure 6.
With the implementation of the "Duration adapted TR" waveform capture method, the user got the choice whether or not waveforms of artificially started hits are captured.

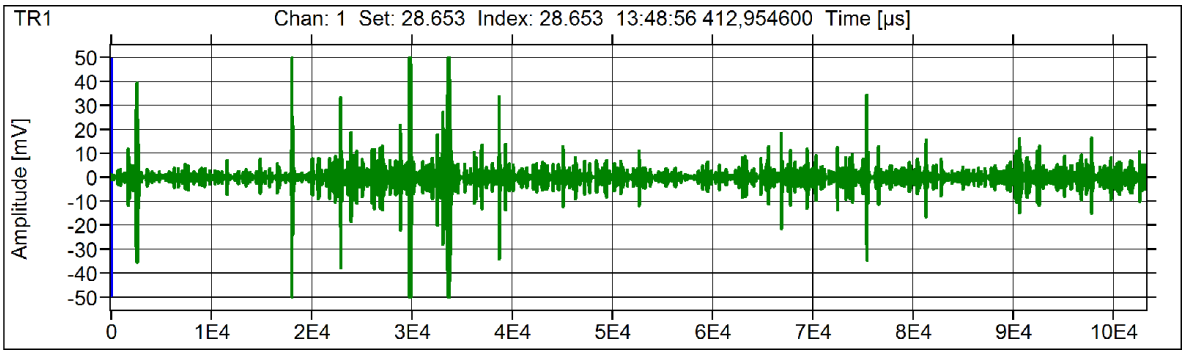

Figure 6. Waveform of a not ending burst, terminated by software to a duration of 104ms.

5 Behavior of "Duration adapted TR" for some special cases

If an absence of threshold crossings had occurred in Figure 6 at t = 5.8 E4 µs (=58 ms) for the duration discrimination time, the AE signal processor would have terminated the 58 ms long hit as usual. With next threshold crossing, a new hit would have been started as usual. Figure 6 would have shown a 58 ms long burst signal then.

If the duration discrimination time is set equal to or greater than "pre-trigger plus post-duration time", no overlap between waveforms will occur. See Figure 5 for this example: Pre-trigger and post duration are 40 µs each.. If duration discrimination time is set to 80µs a next hit will be measured when the threshold crossing occurs one sample after expiration of duration discrimination time. The waveform diagram shows 40µs of post duration samples. Hence the new hit would be associated with a waveform that starts right with the next sample after the last sample shown in the diagram of figure 5.

Pre-trigger-overlap: If DDT is set to 50 µs only and the next burst arrives e.g. 70 µs after the last threshold crossing in Figure 5, the first 10 µs pre-trigger time of the new hit had same data as the last 10 µs post-duration time in Figure 5.

6 User Interface

Duration adapted TR is set up easily in a few clicks. See three check boxes in Figure 7 within the dark red frame.

"**TR Enabled**" is already known. It must be checked, if TR data shall be acquired.

"**Duration adapted TR**" is new, If not checked, traditional TR data capture with constant buffer time applies.

"**Include TR Data for artificial hits (after timeout)**" is also new. If checked, the TR data of artificial hits are acquired. See description of Figure 6 for details.

See the entry field "**Max samples per set**". Enter here the maximum samples you allow for each burst signal. Usually it should cover at least the 104 ms timeout period. You can limit the used storage space to less samples, if desired

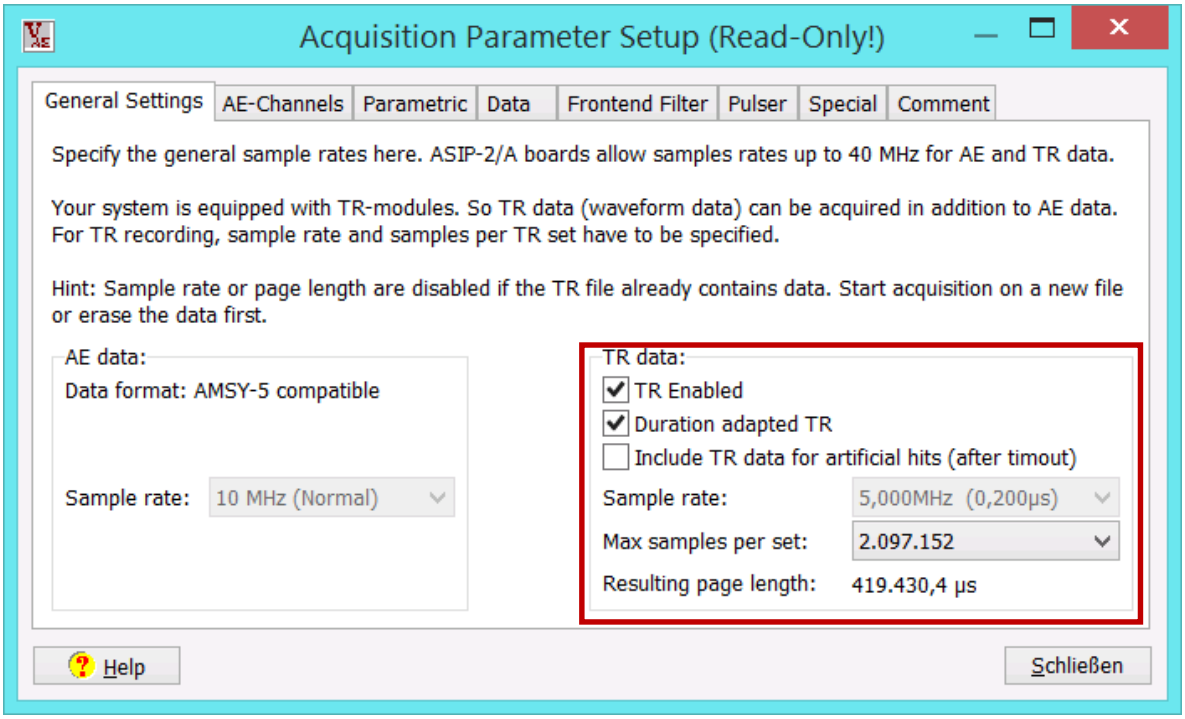

Figure 7. General settings dialogue modified for new capture method

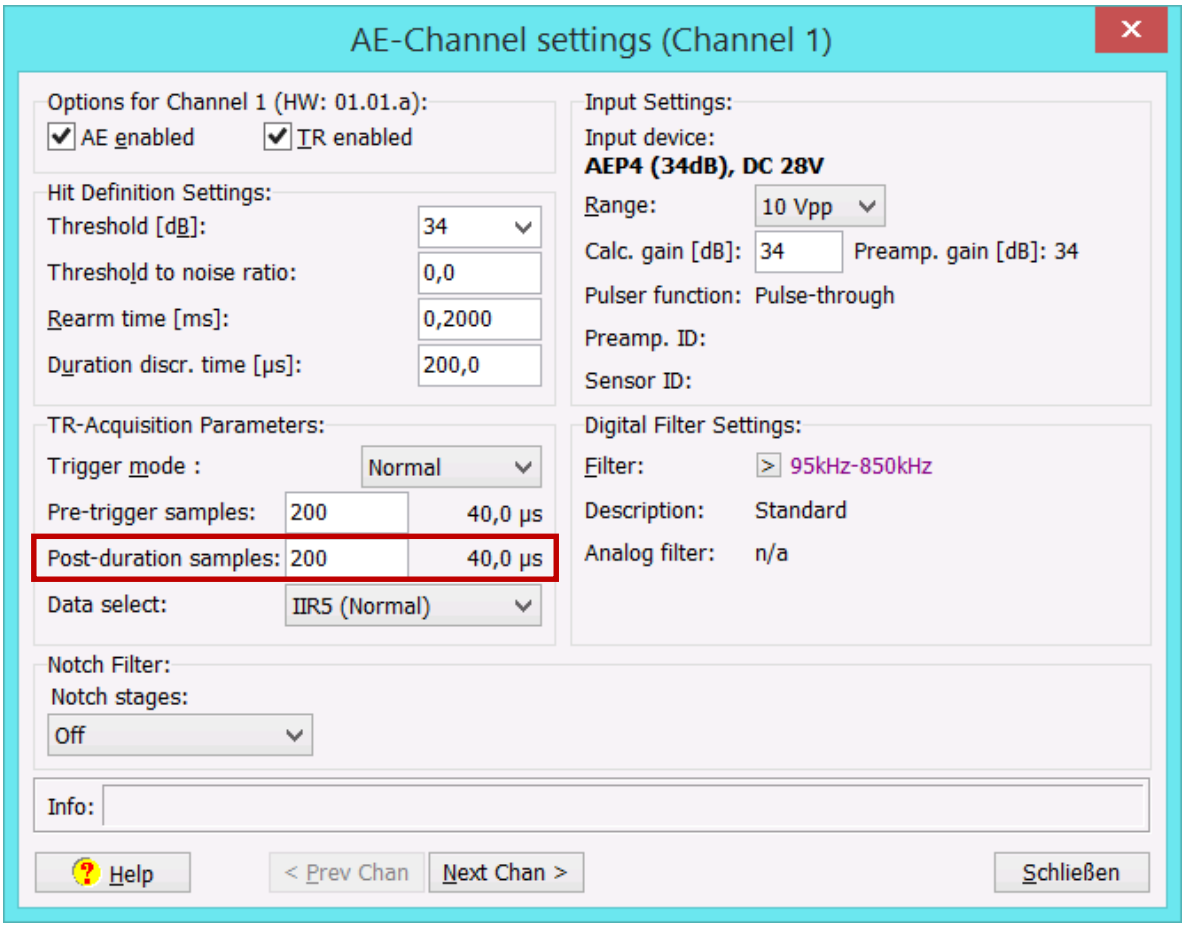

Figure 8. AE channel settings dialogue

In the new AE channel settings dialogue one can define the desired length of the post duration time in number of samples, here 200 samples define (at 5 MHz sampling rate) a length of 40 µs, as indicated in Figure 8.

7 Compatibility

Vallen AE-Suite software released 2014 and later can analyze all files acquired by previous releases. Duration adapted TR-data can be acquired and analyzed using Vallen AE-Suite software released in 2014 and later

There are only the following differences in the acquisition module:

Releases before 2014:	Releases 2014 and afterwards:
No selection of Dur-adapted TR length possible (fixed waveform time only)	User can select either fixed TR-length or duration adapted TR-length per burst
Pool trigger works only on channels in one chassis	Pool trigger can be used with all channels in multi-chassis systems
Waveform of artificially started hits (after timeout) can‘t be seen	User can optionally request TR-data from artificially started hits

8 Conclusion

The new waveform capture method streams the digitized AE signal continuously into TR-Memory until, at a later time, selected burst signals are addressed on the base of hit data (arrival time and duration) and transferred to PC. After passing a TR front end filter one TR-record identified by a unique TRAI is transferred from TR-memory to hard disk drive. The duration adapted TR recording uses resources of bandwidth and memory economically. Short bursts require small memory, long bursts larger memory. Only one burst signal is stored per TRAI. Rearming of a TR trigger is obsolete and no more waveform data is missed because of a rearming process. Additionally since a hardware trigger line is not used anymore, pool trigger works also on channels in different chassis. Furthermore the duration adapted TR recording can also store waveform data of artificially started hits after a timeout.

Our objectives are supporting efforts that AE becomes a most transparent and reliable NDT method. We like to make the usage of AE easier and as foolproof as possible. Another goal was to eliminate still existing bottlenecks in today’s AE technology - for experts, newcomers and the whole society.

References

[1] European Standard EN1330-9:2009 Non-destructive testing – Terminology – Part 9: Terms used in acoustic emission testing