SCHALLEMISSION VON BLEISTIFTMINEN UND GLASKAPILLAREN IN EINEM WASSERBASSIN

ACOUSTIC EMISSION OF PENCIL LEADS AND GLASS CAPILLARIES IN A WATER FILLED BASIN

EMISSION ACOUSTIQUE DE MINES DE CRAYON ET DE CAPILLAIRES EN VERRE DANS UN BASSIN REMPLI D'EAU

Manfred Jarczynski

SUMMARY

The main focus of subproject A6 of the collaborative research centre (SFB 381) is the development of theoretical and experimental fundamentals of acoustic emission analysis, with emphasis on 3D-localization and moment tensor inversion [9]. In this article an experiment aiming to verify and improve these fundamentals is described and first results from analysis are given. A new graphical user interface is being developed in LabVIEW to aid in the analysis.

ZUSAMMENFASSUNG

Zum Arbeits- und Zeitplan des Teilprojektes A6 im Sonderforschungsbereich (SFB) 381 sind für das Jahr 2001 die Schwerpunkte auf theoretische und experimentelle Grundlagen der Schallemissionsanlyse (SEA), sowie auf die Verbesserung der 3D-Lokalisierung und die Automatisierung der Momententensorinversion (MTI) gelegt worden. Hierzu ist ein Modellexperiment zur Überprüfung und Weiterentwicklung der Grundlagen bzgl. der 3D-Lokalisierung und der MTI entwickelt worden. Im Zusammenhang mit der Auswertung ist unter LabVIEW eine neue Benutzeroberfläche in der Entwicklung.

RESUME

Le plan de travail 2001 du sous-projet A6 du SFB 381 a pour axes prioritaires les bases théoriques et expérimentales de l'analyse d'émissions acoustiques, ainsi que l'amélioration de la localisation 3D et l'automatisation de l'inversion des tenseurs des moments (MTI). Dans ce cadre, un dispositif d'essai visant à vérifier et améliorer la localisation 3D et l'MTI a été mis au point. Pour l'analyse des données, une nouvelle interface utilisateur graphique est développée sous LabVIEW.

KEYWORDS: Acoustic emission, model experiment, LabVIEW

INTRODUCTION

The model experiment to improve the localization technique and the moment tensor inversion consists of a water filled acryl glass box with wall thickness of 1 cm. The box has a cubic geometry with a sides of length 30 cm (*figure 1*). A specimen made of brittle material is fixed inside the box on a mount (two different mounts are used) and then is broken by a blunt edge of a stick (3-point-bending). The acoustic emission originated by the rupture of the specimen is detected and measured by piezo sensors attached using wax to the surface of the acryl glass box. A transient recorder is used to record the signals. Two different systems are used: A system developed by W+W and another by ELSYS.

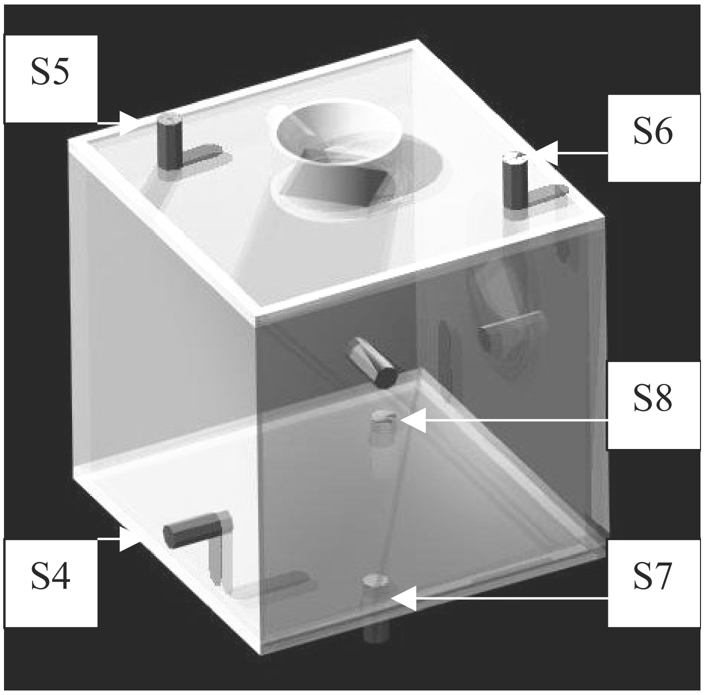


Figure 1: A 3D-figure of the water filled acryl glass box and the connected sensors. The sensors which are used to describe some phenomena in this article are shown here with their numbers.

At least four sensors are required to localize an acoustic emission. If more than four sensors are used, it is possible to find the best localization by the method of minimizing the least square errors [6]. The program Hypo-AE is used to perform these calculations [8].

During the last period of SFB 381 the moment tensor which characterizes the kind of rupture is determined by a program written by T. Dahm [1]. This program is based on the relative moment tensor inversion (RMTI) and requires a cluster of acoustic emissions. A cluster is an accumulation of events having a close proximity to each other in space and a large enough distance from the sensors (far field approximation). The wave propagation path has to be similar for these events. It is necessary to have at least six sensor records to invert on the six independent moment tensor components [2]. To start the inversion, localization of the events and the first peaks of each signal is required. Up to now these peaks had to be detected by an additional software (e. g. WINWAVE or TransAs, for the data of the W+W-recorder or the ELSYS-cards, respectively). Subsequently these peaks are written to an input-file to run the RMTI-program.

The diversity of programs and the incompatible data formats made analysis complicated. To automate the RMTI and to use different transient-recorder systems a new graphical user interface is being developed. LabVIEW is widely-used for these types of tasks and most recorder cards include program libraries for LabVIEW [5]. In the future a complete software, provided by LabVIEW, with features of recording, localizing and inverting on the moment tensor could be possible.

ANALYSIS SOFTWARE

Similar to the graphical user interface of WINPECKER [3], the program developed under LabVIEW consists of one window showing the entire signal and another window, called Zoom-Window, displaying a narrow range around the automatically picked onset time. The zoom factor for this window can be scaled. It is possible to get the cursor position of the onset time in a list to the left of the Zoom-Window by pressing the “PICK”-button. If the analyst disagrees with the automatic onset pick, he can correct the cursor position and use the onset time picked by himself. After picking all sensor signals of one event and clicking the button “Localize ?”, the coordinates and residual errors of the 3D-localization are printed in a text window at the bottom of the screen. The onset times and some more information are saved in a file.

The automatic picking algorithm for the onset times is based on the Hinkley-criterion [4], [7]. This differs from the automatic pick algorithm used by WINPECKER in that an automatic search for the best trend is used. It is also possible to filter noise. This picker developed under LabVIEW is part of the program FreshCon [10]. To automate the RMTI procedure, the mean offset to the onset time and the amplitude of the first peak of the signals are calculated and displayed.

Switches are provided on the left side of the graphical user interface to select the data and its format. The filter parameters used to manipulate the signals to get more accurate onset times from the automatic picking can also be set. The program control is located at the bottom of the screen.

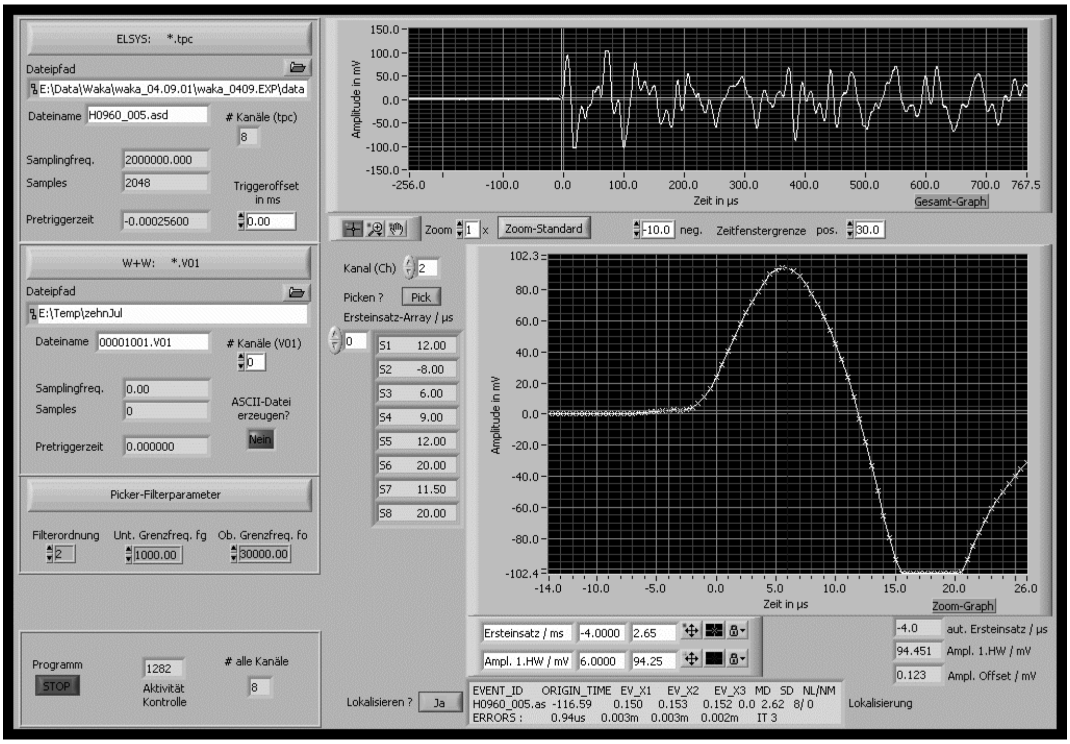


Figure 2: The Control-Panel of the analysis software developed with LabVIEW:

On the left: Settings to select data, formats and filter parameters.

On the right: AE-Signals with onset time (green cursor) and first peak (blue cursor).

In the middle and bottom: List of onset times per sensor, automatic picked onset time, amplitude of first peak, amplitude-offset of the period by the onset time and 3D-localisation with residual errors.

EXPERIMENTS IN THE WATER FILLED BOX

Two different types of mount are used to fix the specimens in the water filled box. One type of mount is made of acryl glass and is shown in figure 3. The specimen, which is a pencil lead or a glass capillary, is fixed by blue plasticine. This mount is friction-locked by a screw at the bottom of the box. This set up is not optimal, because of the coupling between specimen and box via the mount.

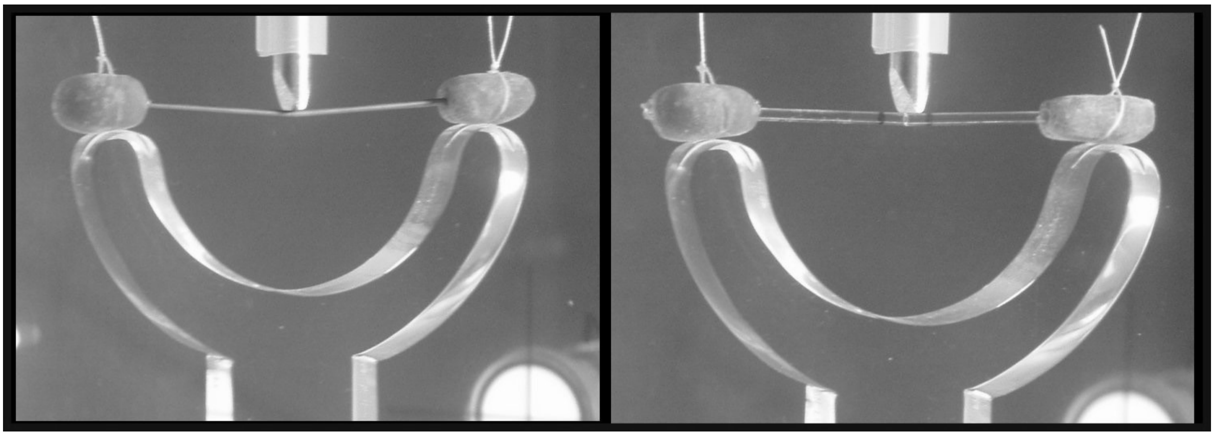
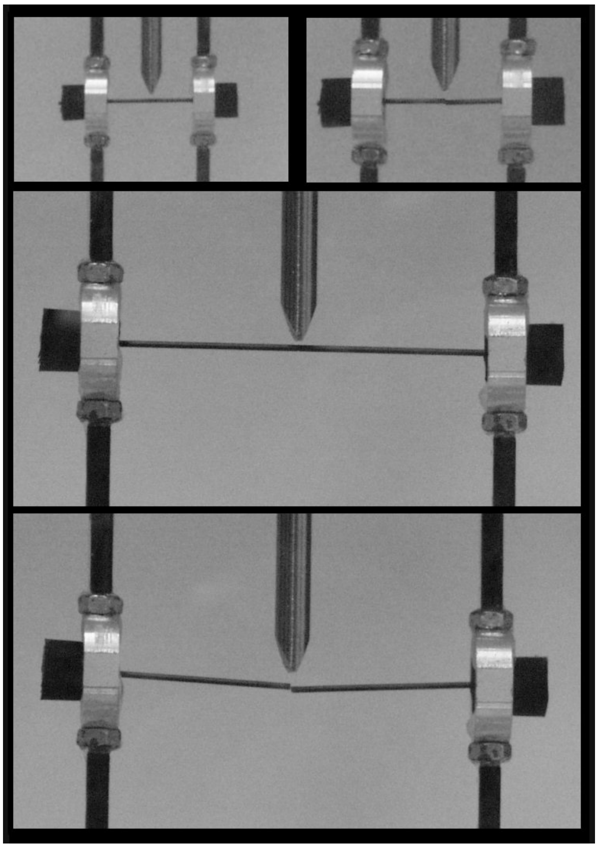


Figure 3: The specimen fixed with plasticine on the acryl glass mount which is friction-locked on the bottom of the box by a screw. Shown are a pencil lead (H 0.9 mm, left) and a batched flow produced glass capillary with notch (Hirschmann, right).



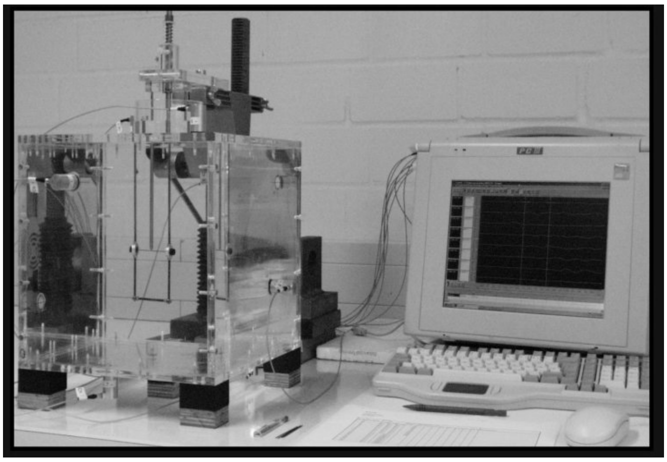


Figure 4: The experimental set up with pendant mounting of the specimen. There are two lengths (25 mm, 50 mm) to fix the specimen in hard rubber. On the left side pencil leads, H 0.9 mm, 30 mm (top) or 60 mm (bottom) are shown before and after the rupture. Notched glass capillaries are also used as specimens.

The other type of mount is shown in figure 4. It is a pendant mounting of the specimen and coupling with the acryl glass is possible only via the water.

The problem of damping between the specimen and the mount is solved using hard rubber. There are two further advantages to this type of mount: the position of the specimen can be adjusted in several azimuth angles and z-positions.

To initiate the rupture of the specimen force is applied slowly using a blunt edge of a steel stick. The pencil lead has been notched with a sharp knife and this notch is positioned at the point of load application. The deflection of pencil lead with 0.9 mm diameter is about 1 mm, pencil lead with smaller diameter has much more deflection and begin to swing after rupture. Most of the experiments were made with pencil leads with 0.9 mm diameter and notched glass capillaries from batch flow production. Some glass sticks were tested as well, but they tended to fragment and the goal of having a small rupture area was lost.

The acoustic emissions are registered by eight or twelve sensors made by Vallen Systems (VS 30). When eight sensors are used, the measurement-cards produced by ELSYS are connected to the sensors; with twelve sensors eight channels are recorded by the W+W transient recorder and four channels by a ELSYS measurement-card. For most experiments the effective range was 200 mV and the trigger threshold was 6-10 mV. The acoustic emissions were sampled over a period of 1024 µs at 2 MHz using the ELSYS-cards and over a period of 8000 µs at 1 MHz using the transient recorder.

DIFFICULTIES IN PICKING THE ONSET TIME

The onset times of the signals of all sensors must be picked for localizing an acoustic emission. It is important to find the correct onset time, because other special points of the signals can be modified by dispersion, which has a spatial dependence on the signal phases. Figure 5 illustrates the difficulties by the means of signals from sensor 5 and 8 recorded during an experiment with pencil lead (hardness H, diameter 0.9 mm, length 60 mm). Glass capillaries have a much more complicated signal form.

Comparing the signal forms, there are obviously large differences in the signals. Additionally there is different phasing of the signals. The signals from experiments with the acryl glass fixing (▽) and the pendant fixing (X) are typical for these sensors and specimens. However, there are many differences in the events of the test series with pendant fixing and azimuth direction of 135°. The reason for this behaviour is not yet known.

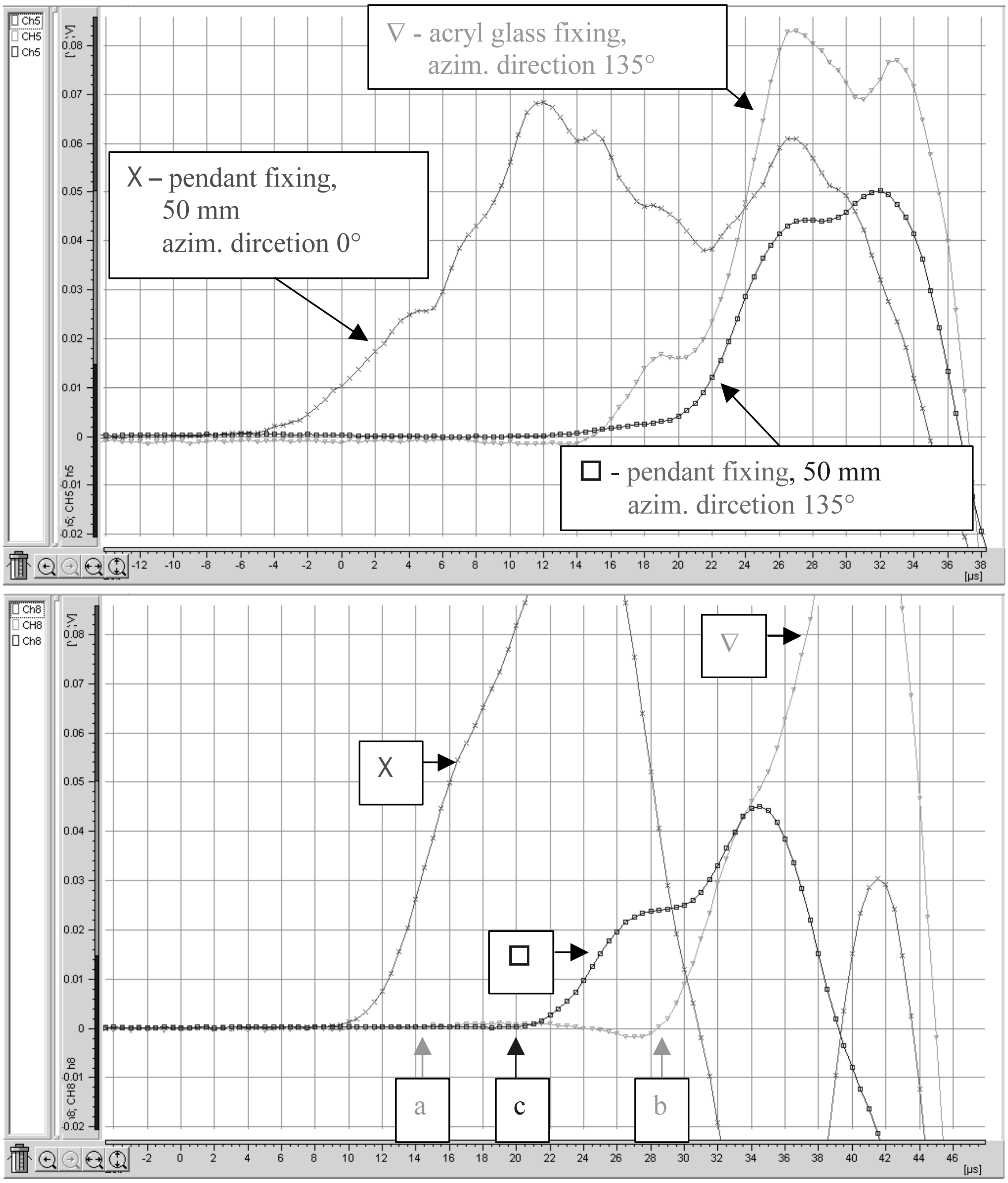


Figure 5: This graph illustrates the problems by picking the onset time and possible influences of the specimen mounting on the signal form. (Top: sensor 5, bottom: sensor 8; time period and amplitudes are scaled comparably)

The signal recorded with sensor 8 labelled with ☐ has a clear onset time, because of the steep rise in amplitude. The signal labelled with ∇ has a rampant amplitude as well, but there is a small oscillation prior to the peak (b). By having a look at the signals of sensor 7 a similar behaviour is found. The localization and a comparison with the real position of the rupture shows that the onset time must be searched at the small oscillation (a). The localization with onset times picked at point (a) are [0.151 m, 0.151 m, 0.146 m] when point (b) is used one obtains [0.151 m, 0.150 m, 0.159 m]. The correct position of the rupture is [0.150 ±0.002 m, 0.150 ±0.002 m, 0.144 ±0.002 m]. The localization of the event labelled with □ and onset time picked at point (c) are calculated by Hypo-AE as [0.151 m, 0.151 m, 0.152 m], while the real position is [0.150 ±0.002 m, 0.150 ±0.002 m, 0.150 ±0.002 m].

One reason for the different signal forms could be searched in the way the specimen is mounted and for that reason the pendant mounting was constructed. Whether the pendant mounting creates other problems must be shown in further analysis of the data. Another reason for the different signal forms could be found in the specimens themselves. There could be different orientations of the rupture surface and there is the possibility of a micro crack forming just before the main rupture.

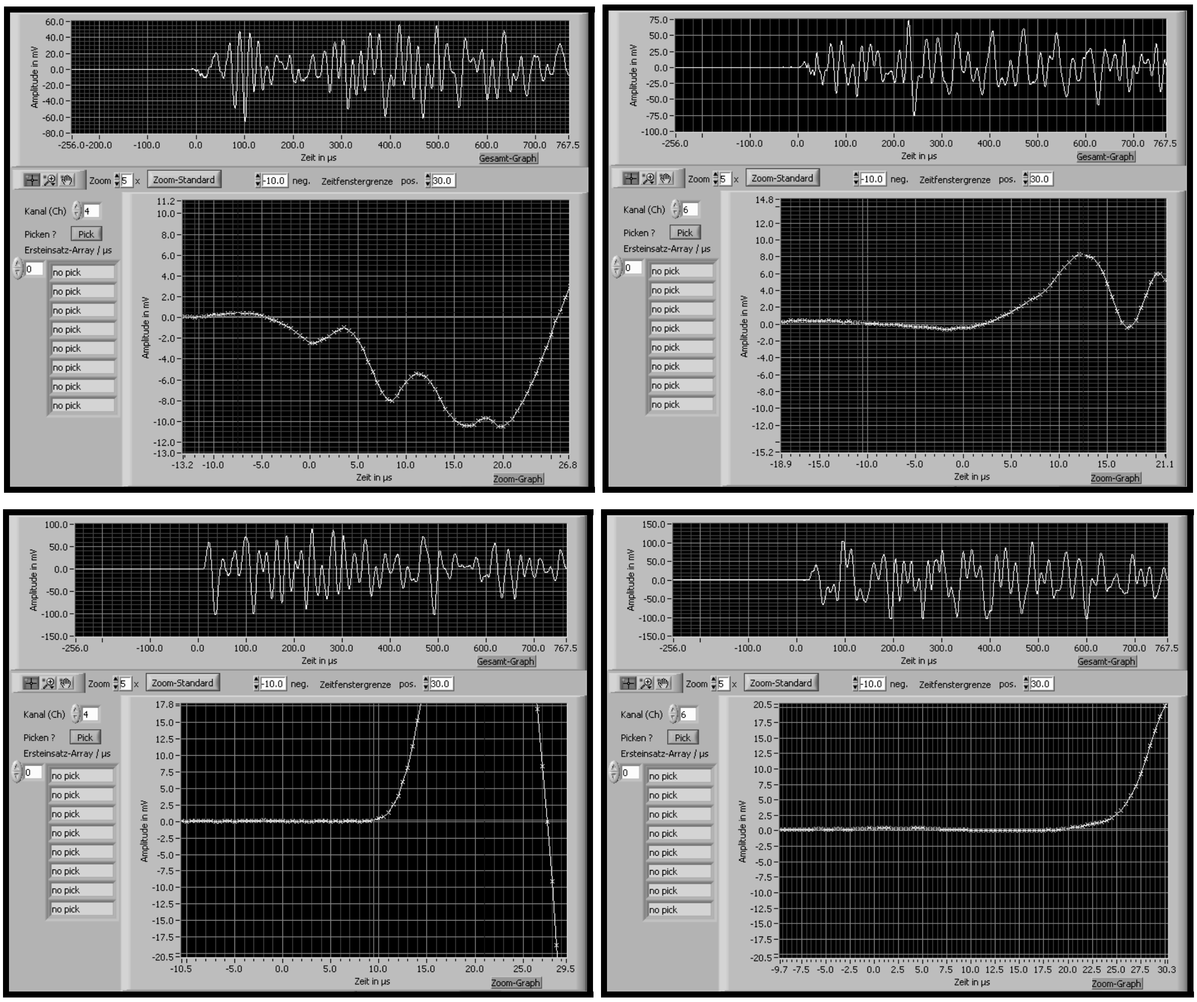


Figure 6: The signal forms of sensor 4 (left column) and 6 (right column) of two events fixed with the pendant mounting in the same test environment.

A first impression of how different the acoustic emission signals are, can be seen in figure 6. A better understanding of the processes producing these signal forms could be obtained by modelling the wave propagation in the water filled acryl glass box. It might be possible to determine the reason for the flat signal onset, for example in the recording of sensor 5 (□ und X).

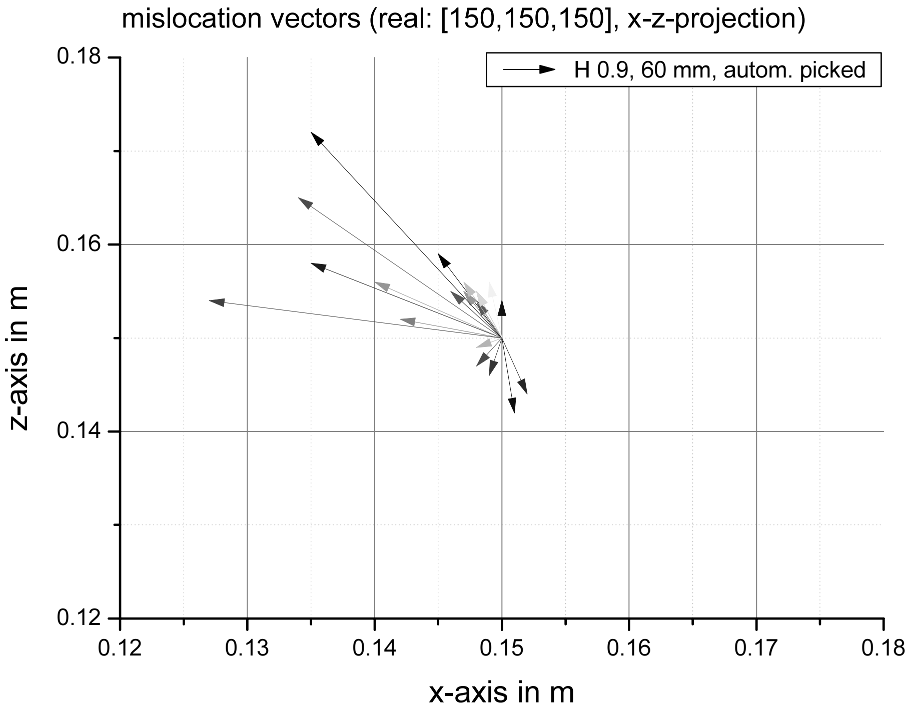
COMPARISON OF LOCALIZATION WITH MANUAL OR AUTOMATIC ONSET TIME PICKING

Although the previous mentioned problems exist, the automatic onset time picking based on the algorithm used in FreshCon was tested in comparison to manual picking. These tests were made with acoustic emissions initiated using the pendant mounting. The results are shown in figure 7 and 8. The figure on the top of each side contains the automatic picking and the one at the bottom the manual picking. The diagrams labelled with (a) and (b) represent mislocation vectors from the real position of the rupture to the localized position as a projection on x-z-plane and y-z-plane. The diagrams labelled with (c) shows the results of localization in three dimensions as a part of the acryl glass box.

Figure 7 includes 27 events that were initiated in the centre of the box at several azimuth angels. The discrepancy between automatic and manual picking appears to be small in the 3D-diagram. It can be viewed better in the error vector diagrams. Up to now there was no time to investigate a possible connection between the size of the error and the azimuth direction of the specimen. It seems, however, that there is only a slight difference between automatic and manual picking as long as the location on the z-axis remains constant.

Localization of nine acoustic emission events with varying positions of rupture along the z-axis is represented in figure 8. While localization using manual picking gets the correct trend of real rupture position, the automatic picking fails miserably. The reason for this malfunction will be investigated in future research, as will dislocations up to 3 cm obtains using the manual picking.

One possibility for the error could be the completely different signal forms of events with the same testing environment (figure 6). More attention had to be given to external noise and motions in the water filled box. The spatial sensor configuration could also have an influence on the signal forms and on the localisation. Using the variation in the z-direction of the pendant mounting makes it possible to analyse this influence more easily than by modifying the sensor configuration.



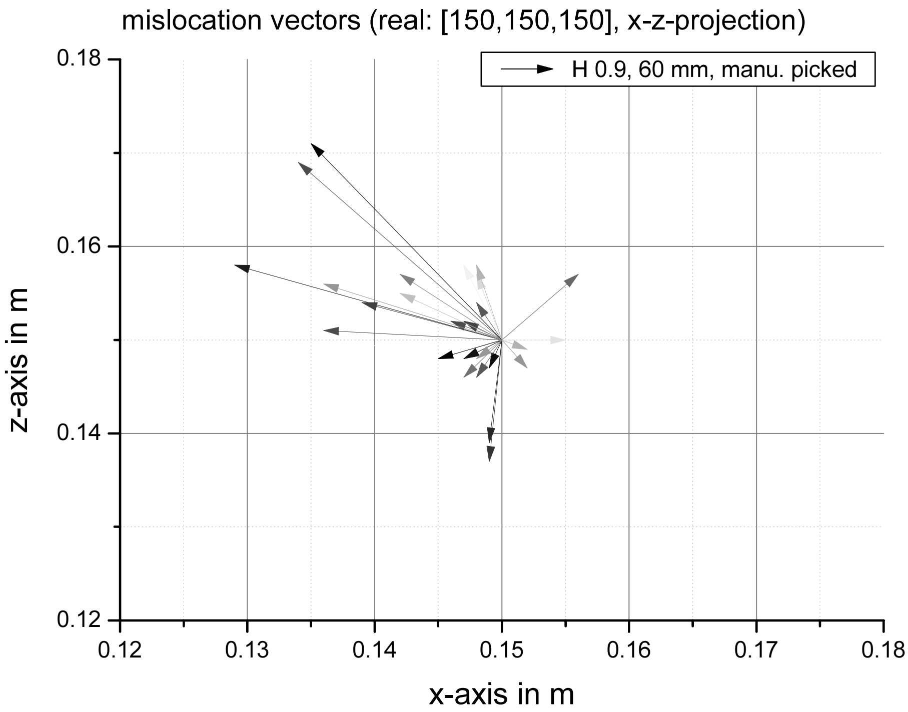
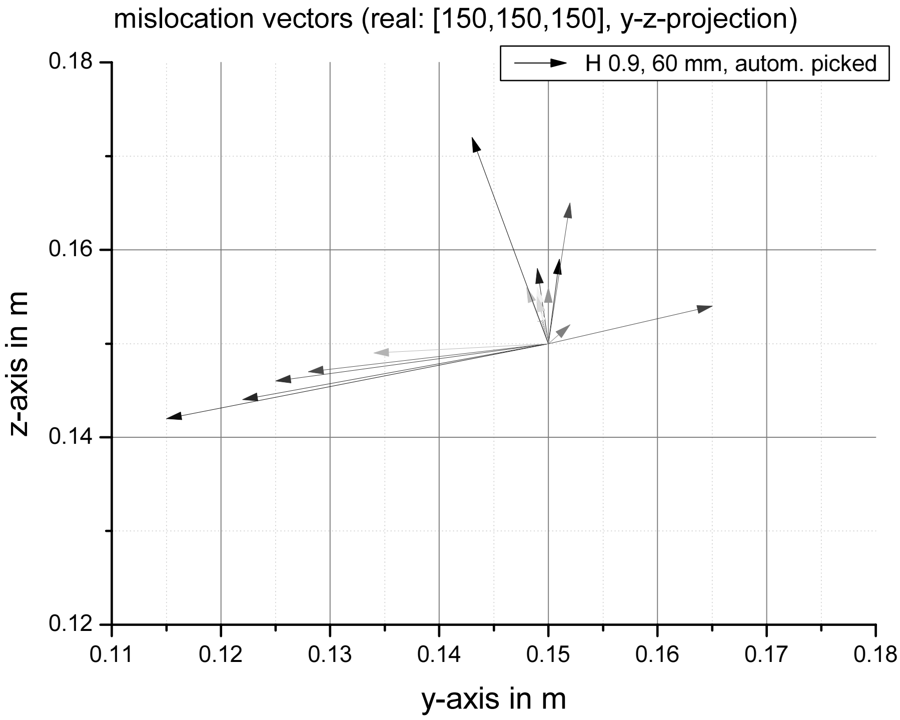


Figure 7a: Represented are mislocation vectors in x-z-projection of acoustic emission events initiated at [0.150 ± 0.002 m, 0.150 ± 0.002 m, 0.150 ± 0.002 m].
Top: Automatically picked onset times
Bottom: Manually picked onset times



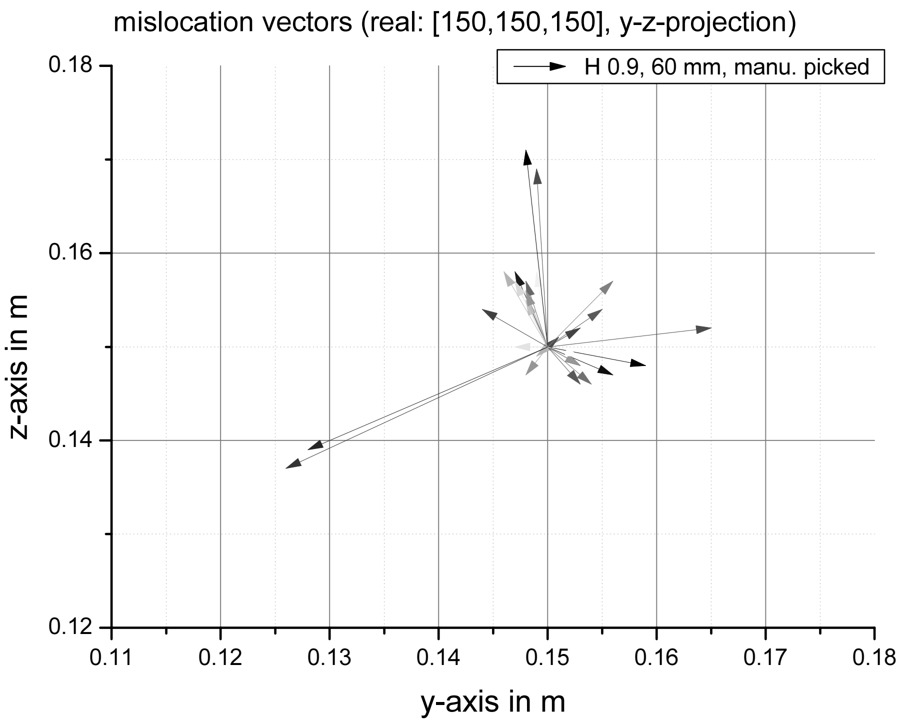
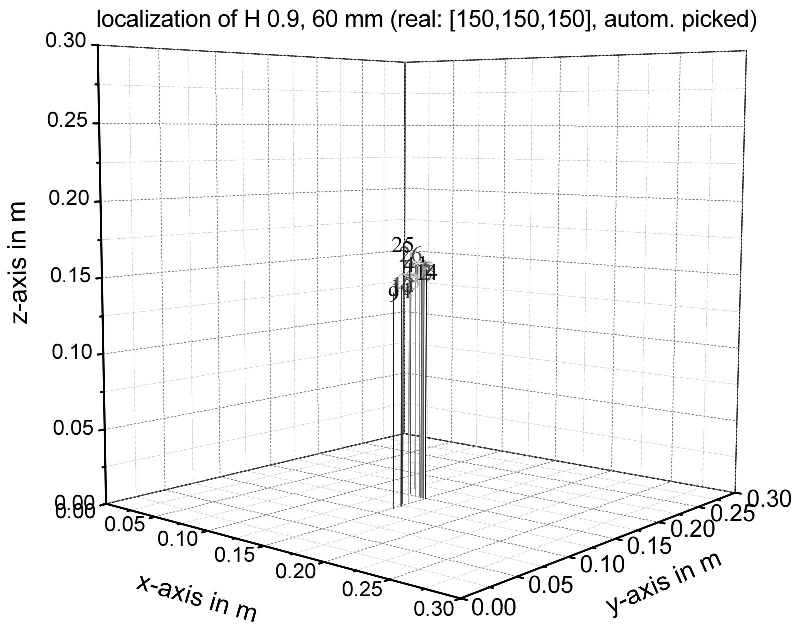


Figure 7b: Represented are mislocation vectors in y-z-projection of acoustic emission events initiated at [0.150 ± 0.002 m, 0.150 ± 0.002 m, 0.150 ± 0.002 m].
Top: Automatically picked onset times
Bottom: Manually picked onset times



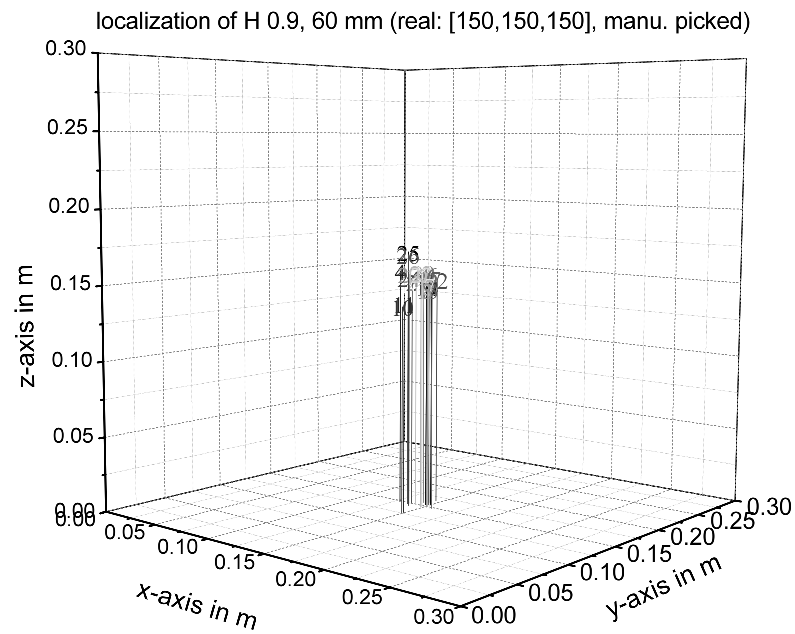
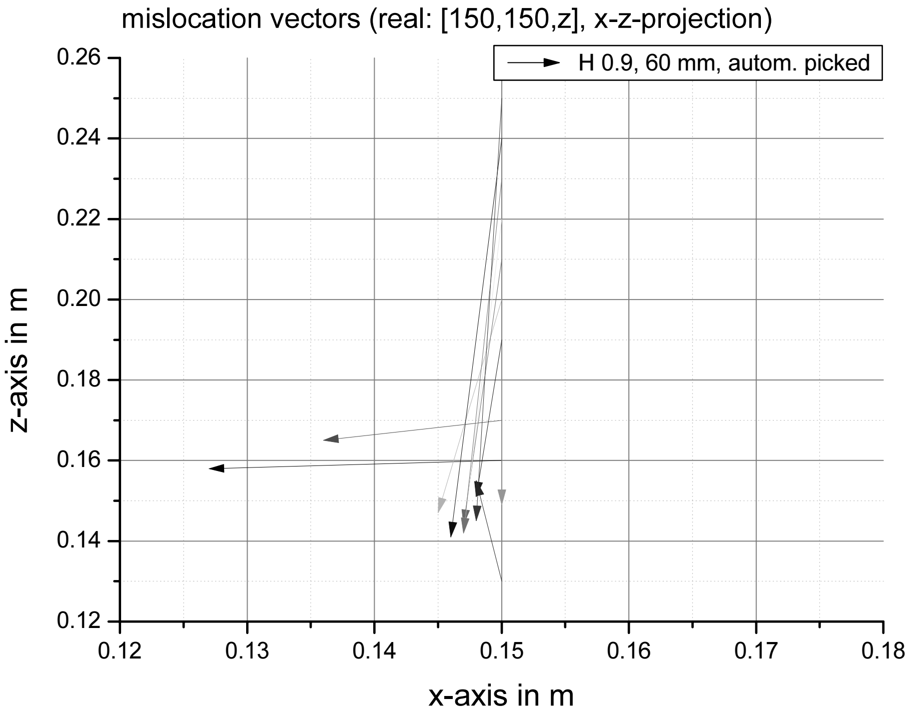


Figure 7c: Represented are the localizations of acoustic emission events initiated at [0.150 ± 0.002 m, 0.150 ± 0.002 m, 0.150 ± 0.002 m].
Top: Automatically picked onset times
Bottom: Manually picked onset times



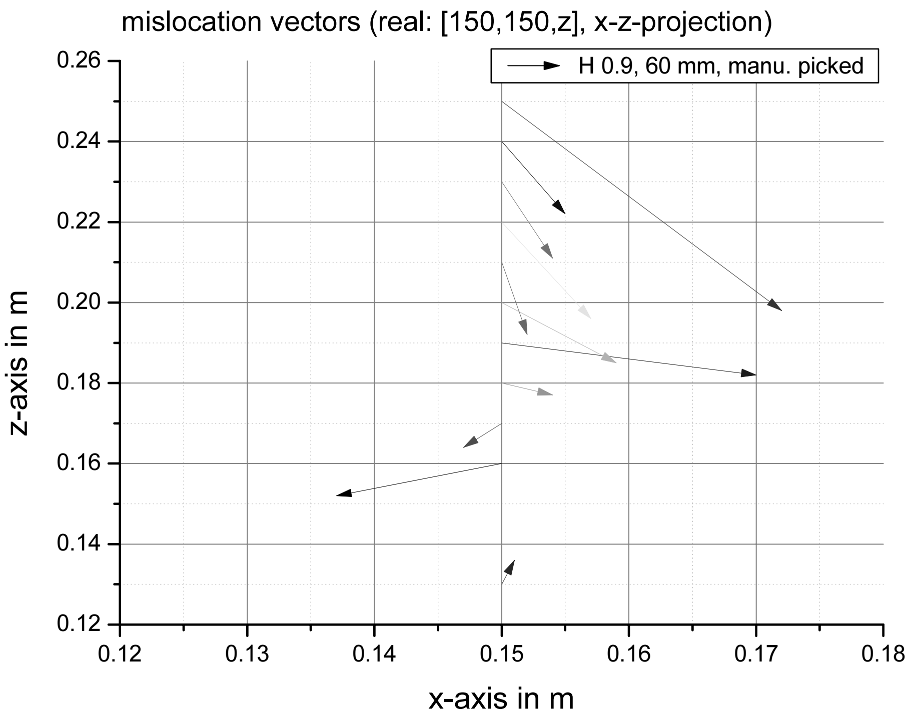
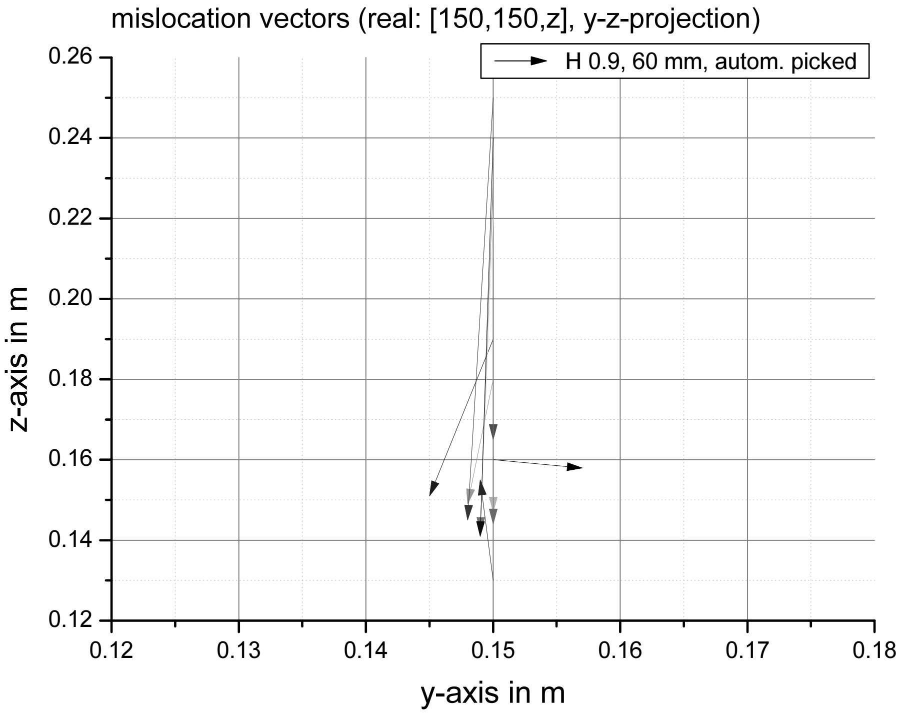


Figure 8a: Represented are mislocation vectors in x-z-projection of acoustic emission events initiated at [0.150 ± 0.002 m, 0.150 ± 0.002 m, z ± 0.002 m].
Top: Automatically picked onset times
Bottom: Manually picked onset times



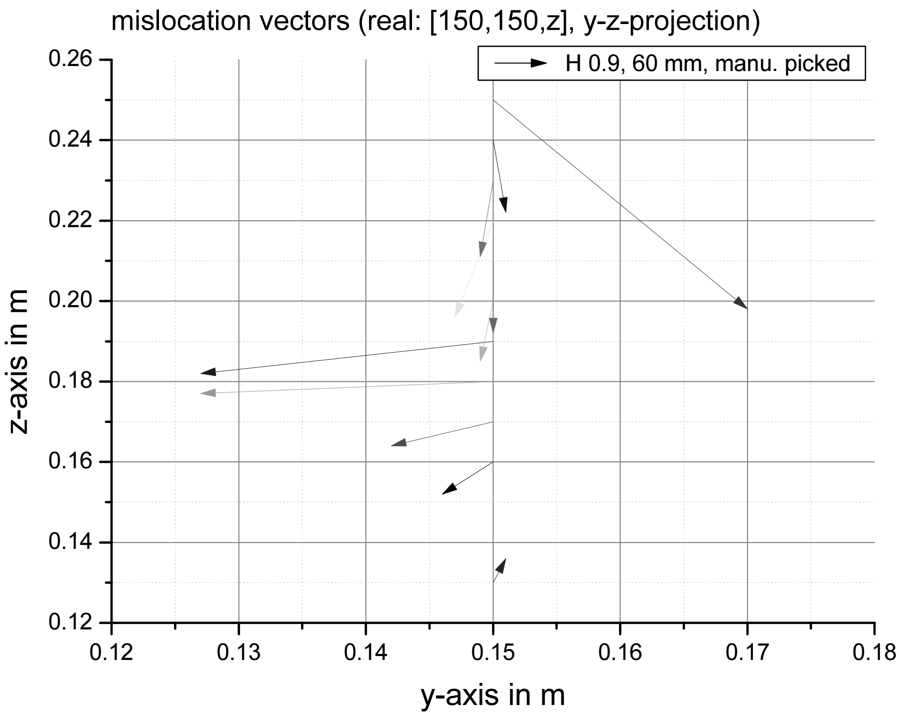
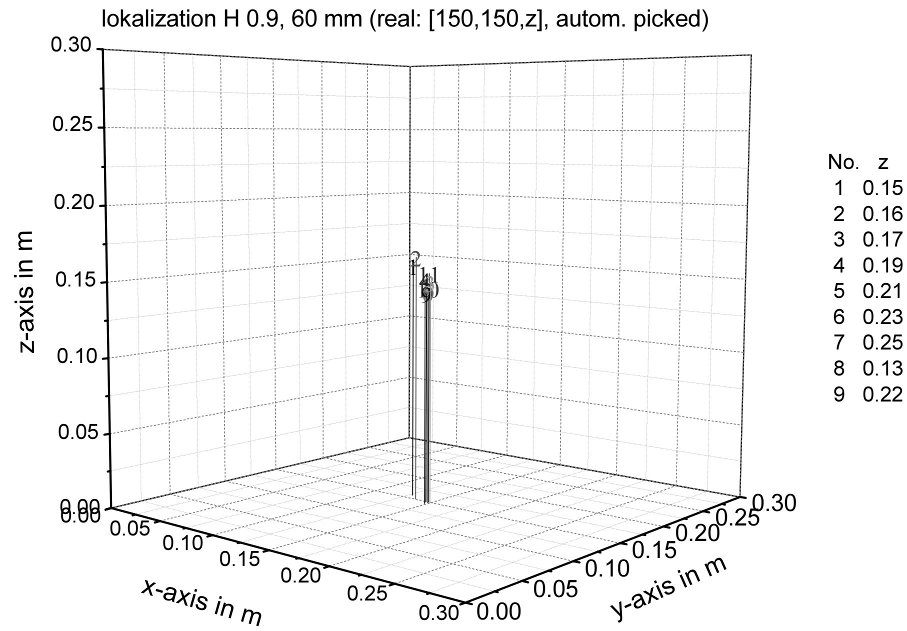


Figure 8b: Represented are mislocation vectors in y-z-projection of acoustic emission events initiated at [0.150 ± 0.002 m, 0.150 ± 0.002 m, z ± 0.002 m].
Top: Automatically picked onset times
Bottom: Manually picked onset times



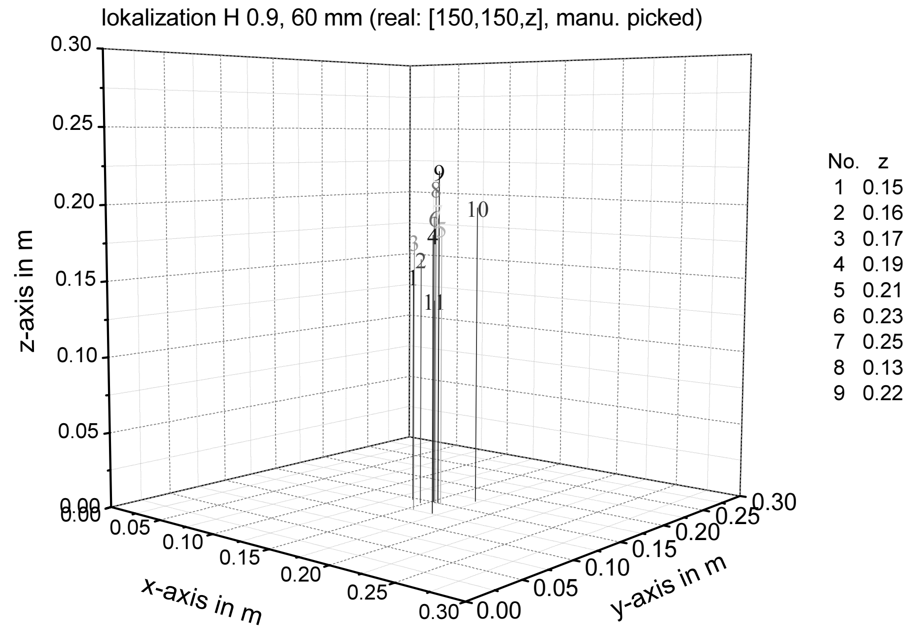


Figure 8c: Represented are localizations of acoustic emission events initiated at [0.150 ± 0.002 m, 0.150 ± 0.002 m, z ± 0.002 m].
Top: Automatically picked onset times
Bottom: Manually picked onset times

CONCLUSIONS AND FUTURE WORK

The rupture of pencil leads or glass capillaries at known positions in a water filled acryl glass box can be studied using acoustic emissions. A new mounting set up makes it possible to initiate the rupture at different positions along the z-axis and at different azimuth angles. Analysis of initial experiments shows that the wave propagation is complex and the difficulties are greater than expected. Modelling of the wave propagation could help to understand the complex behaviour.

Due to the difficulties experienced it is necessary to first refine the localization procedures and later on, after developing a user-friendly analysis software, the relative moment tensor inversion. In particular the dependency of the methods leading to clusters and near field terms can be easily investigated. In this respect the analysis of the existing data must be continued and new data must be accumulated in future experiments.

Comparison of localization with automatic and manual picking of onset times points out that many questions remain unsolved. Failure of the automatic picking when the position along the z-axis is varied must be analysed.

In the future it is planned to place some disturb bodies in the path of wave propagation and study their influence on localization and moment tensor inversion.

REFERENCES

[1] Dahm, T.: Relativmethoden zur Bestimmung der Abstrahlcharakteristik von seismischen Quellen. Dissertation Universität Karlsruhe (1993).

[2] Große, C. U.: *Grundlagen der Inversion des Momententensors zur Analyse von Schallemissionsquellen*. Aus: Werkstoffe und Werkstoffprüfung im Bauwesen, Festschrift zum 60. Geburtstag von H.-W. Reinhardt, Libri-BOD, Hamburg (1999), S. 82 - 105.

[3] Große, C. U.: *Winpecker – Program for the 3D-localization of Acoustic Emissions and the Automatic Determination of Onset-Times*. Instruction Manual (2000).

[4] Große, C. U., Reinhardt, H.-W.: *Schallemissionsquellen automatisch lokalisieren*, Die Materialprüfung (Jahrg. 41, 1999), S. 342 - 347.

[5] Jamal, R., Krauss, P.: *LabVIEW – Das Grundlagenbuch; Programmierung, Meß- und Regelungstechnik*, Prentice Hall (1998).

[6] Lay, T., Wallace, T. C.: *Modern Global Seismology*. Academic Press (1995).

[7] Mikhailov, N. Große, C. U.: *An Automatic Picker of the Onset Time of Acoustic Emission Signals*. Otto-Graf-Journal, Vol. 6 (1995), S. 168 - 187.

[8] Oncescu, L., Große, C. U.: *Hypo-AE – A Program for the Localization of Hypocenters of Acoustic Emissions*. Dokumentation zur Software für PC und Workstation, Rev. 2.0 (1996).

[9] Reinhardt, H.-W., Große, C. U.: *Detektion und Lokalisierung von Rissen und Fehlstellen in Stahlbeton und Faserbeton.* SFB 381, Teilprojekt A6, Universität Stuttgart, Finanzierungsantrag 2001-2003 (2000), S. 283 - 304.

[10] Ruck, H.-J., Große, C. U., Reinhardt, H.-W., Bahr, G., Schlaich, P. *FreshCon 2.0 – Software for Data Acquisition and Data Analysis.* Otto-Graf-Journal Vol. 11 (2000), S 49 - 58.