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AN EXAMPLE OF POSSIBLE NON-LINEAR EFFECTS ON SEISMOACOUSTIC PULSES SPECTRA

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Summary : An example of observed non-linear effects on the seismoacoustic pulses spectra is presented. Comparission of non-linear superposition with the amplitude modulation is proposed for the interpretation.

Keywords : seismoacoustics

Introduction

The laboratory seismoacoustic measurements on the loaded rock samples are used to study the importance of different physical parameters (the contact conditions on fault, the value of contiguous pressure, the rate of loading and the material composition) for the seismic energy release. The interpretation of SA records enables to study the seismic source mechanism, the dynamic properties and the frequency contents with the connection to the stress-strain state. This short communication deals with some non-linear effects observed in the frequency spectra of SA pulses. The comparisson of theoretical and real signals is presented.

The laboratory measurements

The laboratory data presented were collected in a special experiment designed to simulate stick-slip seismic source conception (see Fig.1). Detailed description is given in Aksenov at all. (1992). Monitoring SA emission was realized by a piezoelectric accelerometer (200 kHz) glued on the model surface. Sampling rate was 1 MHz, 12 bit A/D convertor (transient recorder R 1200 M, RAPID SYSTEMS) was used.

The amplitude spectra of recorded SA events were calculated as an absolute value of Fourier transform of recorded acceleration time course x(t)

$$|F(\omega)| = \sqrt{(\mathrm{Re}\,F)^2 + (\mathrm{Im}\,F)^2} \quad , \text{ where}$$

$$F(\omega) = \int_{-\infty}^{\infty} x(t)\,(\cos \omega t - i \sin \omega t)\,dt \;.$$

The calculations were done according to the FFT algorithm (1024 points).

Some of the amplitude spectra exhibited a course typical for the case of nonlinear superposition. That means the seismic wave interference doesn't confirm the principle of linear superposition. Khavroshkin (1987) showed, that the spectrum of the seismic interference wave produced by two seismic exploration vibrators may involve the local maxima on frequencies equal to the sum and the difference ($f_1 \pm f_2$) and the harmonics of vibrators frequencies f_1 , f_2. We can observe two local maxima (f_1+f_2 and f_1-f_2) around the central local maximum at frequency f_1 on the course of the spectrum . The surrounding maxima correspond to the frequencies, which are exactly symmetrical with respect to the central maximum. In the Fig. 2 there are two examples of such effects in the recorded SA signals on the stick-slip seismic source model with sandstone rock sample. Aljeskin at all (1987) have revealed, that under some conditions (e.g. close to seismic source) the non-linear relation between stress and strain can cause the non-linear superposition of propagating seismic waves, which resembles the processes of amplitude modulation and demodulation of the signals.

A comparisson of linear and non-linear superposition of theoretical and real records

To illustrate the non-linear superposition based on the amplitude modulation we can use instaed of SA pulse its approximation by harmonic attenuated signal. In the Fig. 3 two different theoretical pulses (according to Berlage) $F(t) = a_0 t \exp(-\beta t) \sin(\omega_0 t)$ with added noise are showen. Frequencies ω_0 are 75 kHz (model record A) and 40 kHz (model record B).

In the lower left part of Fig. 3 the algebraic sum of the records A and B which represents the case of principle of superposition validity is presented. The spectrum of such interference signal embodies only the original frequency components.

The non-linear superposition of these records A and B is shown in the lower right part of Fig. 3. The interference wave calculation rest on the amplitude modulation of the A signal with the B signal. If we have two signals :

$$A(t) = A_1 t \exp(-\beta_A t)\sin(\omega_A t+\varphi_A) \quad \text{and}$$

$$B(t) = B_1 t \exp(-\beta_B t)\sin(\omega_B t+\varphi_B) \quad , \text{ then the}$$

amplitude modulation of signal A with signal B can be expressed

$$A_M(t)=[A_0 + B(t)]\ t \exp(-\beta_A t)\sin(\omega_A t + \varphi_A).$$

After rearangement

$$A_M(t)= A_0\ t \exp(-\beta_A t)\sin(\omega_A t + \varphi_A) + B_1 t^2 \exp((-\beta_A-\beta_B)t)\{\cos[(\omega_A-\omega_B)t+\varphi_A-\varphi_B] - \cos[(\omega_A+\omega_B)t+\varphi_A+\varphi_B]\}/2 .$$

From the last expression it is clear, that the spectrum of modulated signal involves maxima at frequencies ω_A, $\omega_A-\omega_B$ and $\omega_A+\omega_B$. The components $\omega_A-\omega_B$ and $\omega_A+\omega_B$ do not really exist on the input of such a non-linear system.

In the Fig. 4 there are SA signals recorded from the model of stick-slip seismic source, fine grained magnesite rock sample was used. The spectrum of record no 019 has a maximum on frequency equal to 75 kHz, record no 322 has its maximum on frequency 35 kHz.

The linear superposition of this two records is presented in the lower part of Fig. 4. The algebraic sum was realised with an appropriate time shift in consideration of maximum coherence in the beginning part of the time courses of the SA pulses.

The non-linear superposition (see Fig. 4, the lower right part) was calculated with the very same time shift as above. The amplitude spectrum involves the peaks on frequencies 40 kHz, 75 kHz and 110 kHz. The most meaningful difference between the linear and the non-linear type of superposition is the occurence of 110 kHz maximum at one of the compared spectra of these two interference signals.

The Fig.5 enables to compare real record no 067 (from the same experiment and rock material as in Fig. 4) with the computed non-linear superposition of records nos 019 and 322. It seems, that both the time courses of records compared and especially their spectra are very similar. Comparisson of this type were succesfully completed also in other cases of the SA events records on different rock samples and different texture types. It seems, that on certain stress-strain conditions and in connection with the specific seismic-source type the non-linear superposition which resembles the amplitude modulation can play an important role in SA measurements on the loaded rock samples.

We can also note that in the case of recording SA impulses with transient recorders with lower dynamics (8 bit A/D convertor) the effects of non-linear superposition are offen nonmeasurable owning to unfavourable ratio of amplitudes of particular frequency components

Conclusion

The analysis of SA events spectra has revealed the existence of amplitude modulation effects. The amplitude modulation does not confirm the linear principle of superposition validity and can be cosidered as a consequence of the non-linear stress-strain relation. According to Aksenov at all.(1992) the amplitude modulation is one of the non-linear effects in connection with seismic source on specific stress-strain state.

Acknowledgement

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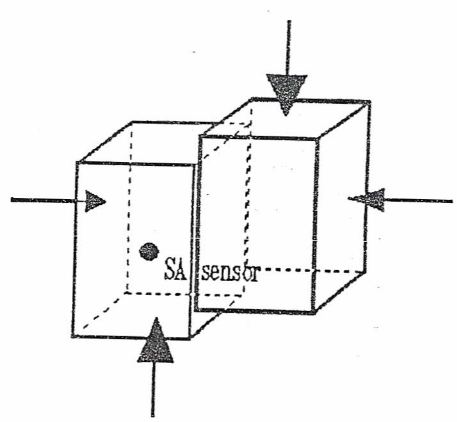

Fig.1 The model for simulation stick-slip seismic source.

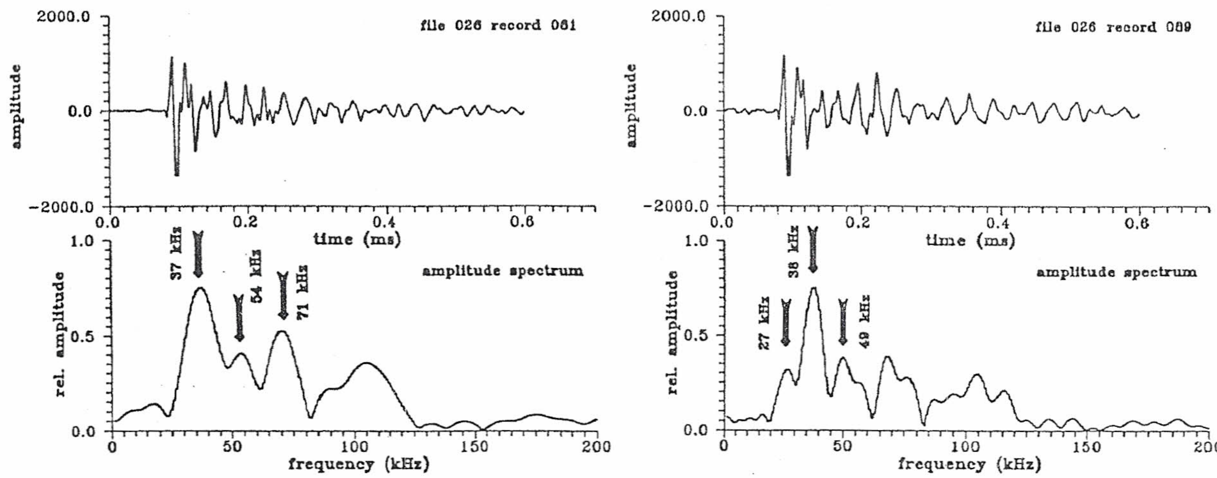

Fig.2 An example of recorded SA signals and their amplitude spectra from the stick-slip seismic source model with sandstone rock sample.

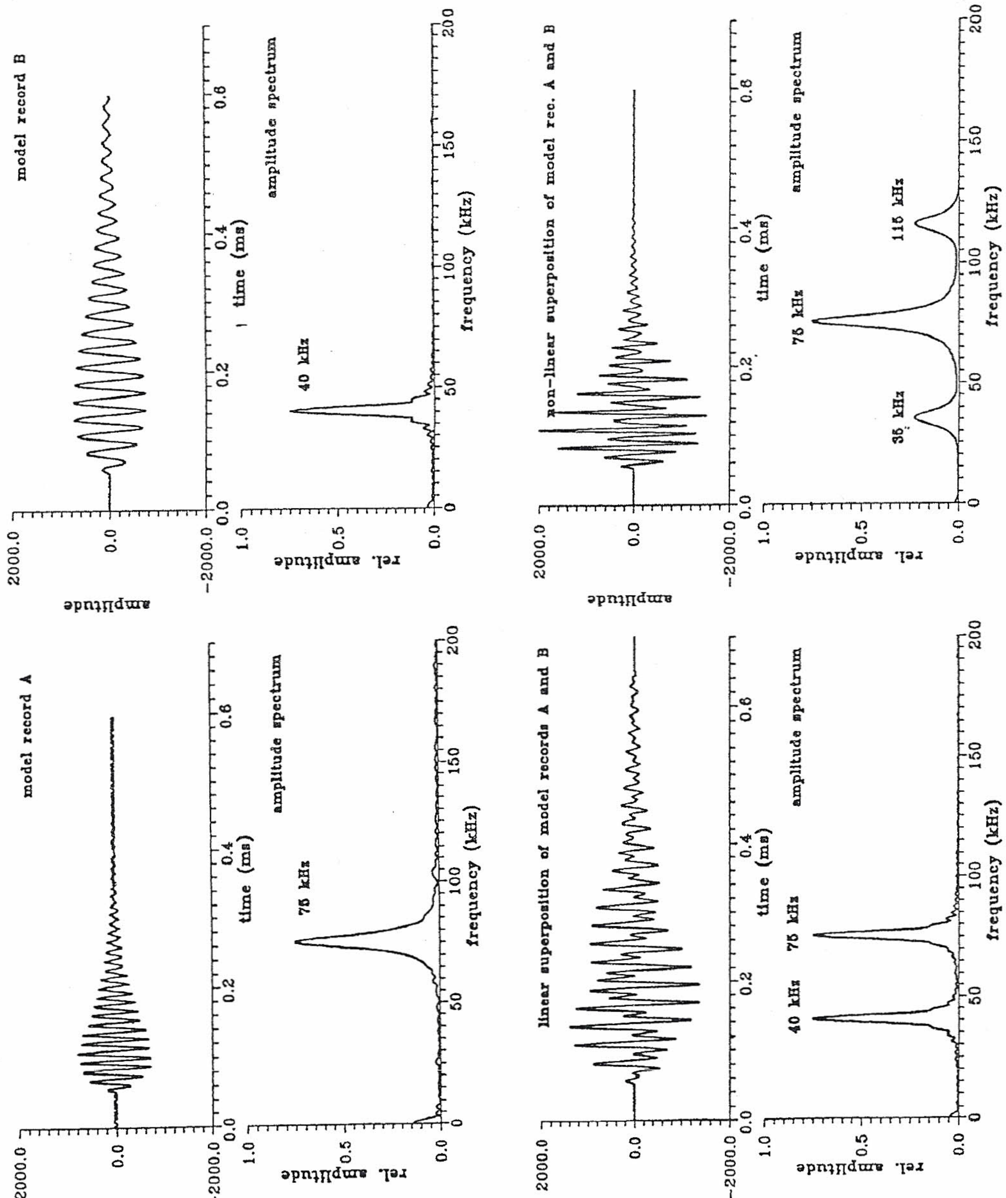

Fig.3 Computed pulses (according to Berlage $F(t) = a_0 t \exp(-\beta t) \sin(\omega_0 t)$) and their amplitude spectra. Lower part: linear and non-linear superposition of above theoretical pulses and their spectra.

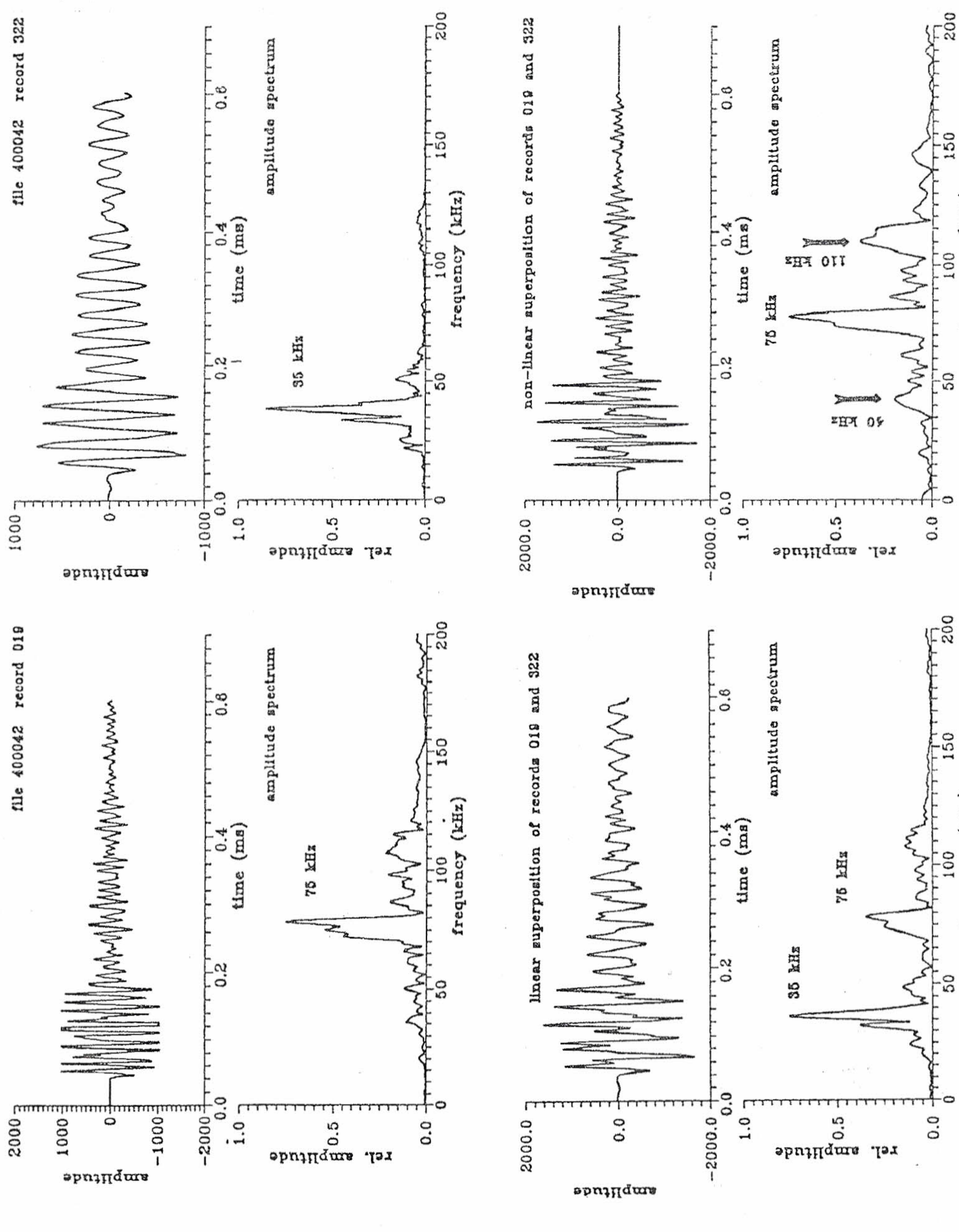

Fig.4 Recorded SA pulses and their amplitude spectra from the model of stick-slip seismic source, fine grained magnesite rock sample. Lower part: linear and non-linear superposition of above pulses and their spectra.

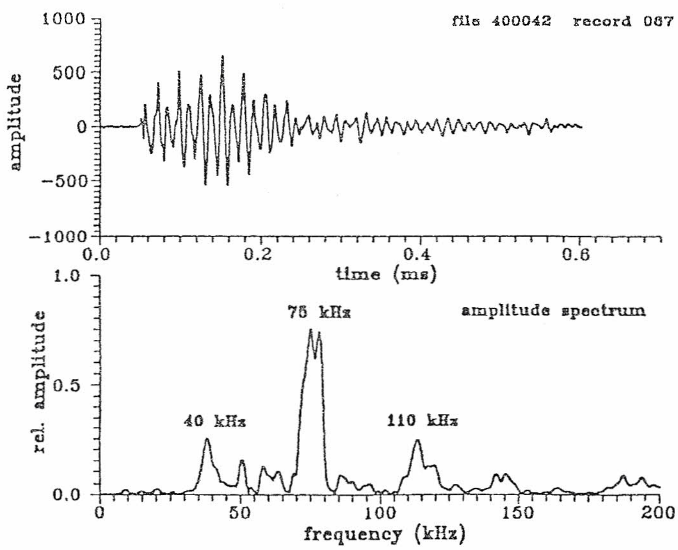

Fig.5 An example of recorded SA signal and its spectrum from the stick-slip seismic source model, fine grained magnesite.