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EXPERIMENTAL TECHNIQUES FOR THE STUDY OF THE CYLINDRICAL RODS COAXIAL IMPACT

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Abstract: In this paper are described some techniques and experimental models for deformable bodies' impact analysis, based on the longitudinal wave's propagation theory. Also methods for experimental data processing are presented (Fourier transformation, wavelet analysis).

1. INTRODUCTION

Experimental investigations in the field of impact have been performed for a variety of purposes such as: assessing the validity of a proposed theory or the accuracy of an assumed model of material behavior or analysis of phenomena. This category includes experimental studies pertaining to the Hertz law of contact, the analytical approximations of wave processes in elastic solids, and the theories of plastic or visco-elastic wave propagation. In the last case, such experiments have been invaluable in demonstrating the limited applicability or complete invalidity of some of the proposed analyses.

Some techniques for deformable bodies' impact analysis based on the longitudinal wave's propagation theory and the instrumentation for measuring its effects are briefly described in the paper. Also methods for experimental data processing are presented.

2. METHODS AND MEANS FOR ANALYSIS AND MEASURING OF IMPACT EFFECTS

Impact at low velocities can be readily achieved by a guillotine apparatus for transverse impact of beams [1]. Goldsmith realizes a serial of experiments using a ballistic suspended body. Representative examples of this technique are the longitudinal collinear impact (Fig.1) and the collision of two spheres.

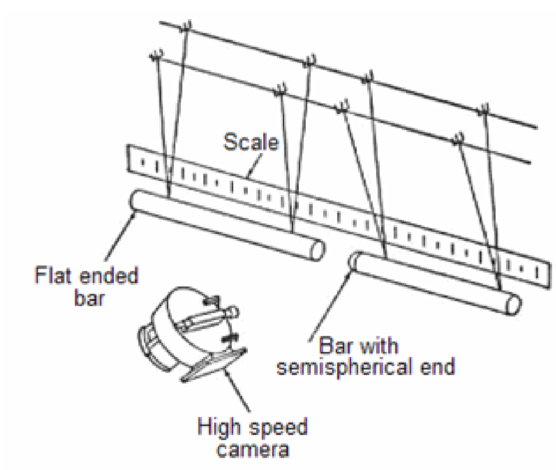

Fig.1. Ballistic suspension for the longitudinal impact of two rods

Impact at higher velocity are usually attained by the firing of projectiles from air guns or specially designed ultra-speed devices, using the reaction of a compressed light gas or electromagnetic methods of bullet acceleration.

Generally, the quantities which are most frequently measured in an impact experiment are: the displacements of the striking bodies, the contact phenomena (such as the duration of impact) and the stress waves generated in the bodies, as result of the collision.

The first measurement of the motion of striking bodies during experimentally tests were obtained by visual observations of the height of fall and rebound.

Small displacements, such as transverse beam deformations, were initially determined by means of mechanical instruments, like scratch extensometers or dial gauges. However, the inertia and friction of these devices renders their accuracy unsuitable for precision measurements. Satisfactory results have been obtained with the development of electrical, foto-electric or photographic techniques. The first two methods involve the completion of an electric circuit. Full-field photography of the event permits the observation of the motion of the bodies subjected at the impact without a previous knowledge of their exact trajectory before and after impact. The permanent strain distribution produced at the surface of the bodies may be readily determined from the spacing of a grid ruled on the specimen.

The duration of the contact can be accurately measured from the pulse produced by the closing of an electrical circuit composed of the striking bodies and a voltage source.

Stress wave observation can be realized by means of electrical, optical and mechanical methods.

The most practical electrical devices for stress pulse measurement are resistance wire strain gauges, piezo-electric gauges and condenser gauges. The signals from these transducers are generally recorded on a cathode-ray oscilloscope or an acquisition data board. Strain gauges started to be used to measure the displacements of surfaces by Petterson, Campbell, Hauser et al, in the mid 1950s [3]. Strain gauges have a disadvantage because they must be cemented to a specimen and their law intrinsic signal strength requires considerable amplification. Other disadvantages include their integrated response over a finite gauge length, their restricted use to elastic or at best small plastic deformations of the specimen and the fidelity of the recorded pulse shape due to amplifier characteristics and the effect of the bonding material. The gauge itself exhibits an excellent frequency response. Their advantages include the simplicity of operation and the possibility of arranging several gauges so as to record only a particular component of a pulse. Numerous investigations have been conducted to determine the dynamic characteristics of strain gauges, including a direct comparison of their signal with the response of other transducers ([4], [7]).

One of the most common methods of optical stress measurement is the use of the photo-elastic technique, where a beam of polarized monochromatic light exposes a fringe pattern in a stressed specimen ([4], [8]).

The stress-time dependence of a repeatable elastic pulse in a bar, generated by longitudinal impact can also be measured mechanically. Hopkinson performed the pioneering work on determining the shapes of impulses traveling down rods, the device consisting of a long steel cylindrical rod, a short steel billet and a ballistic pendulum, to convey a force pulse to a force transducer became known as the “Hopkinson pressure bar”. By impacting one end of the rod, a compressive pressure wave of finite length is generated inside the rod. At the far end of the rod a short steel billet is attached, held by only a thin layer of grease. Hopkinson’s idea was that as the compressive wave traversed down the bar, through the greased joint, and into the billet the wave would be reflected at the far end as a pulse of tension. Since the grease could not withstand any appreciable tensile loads, the billet would fly off with a definite momentum, measured with a ballistic pendulum. The time over which this momentum acts is the round trip time of the longitudinal wave in the billet. By running several tests of identical magnitude but different length cylindrical billets, a series of pressures-time curves were generated describing the impact event. Hopkinson was always capable of determining the maximum pressure and total duration of these impact events, but exact pressure-time curves were sketchy.

A second pressure bar was added to Hopkinson's original apparatus by Kolsky, hence the name "split Hopkinson bar" ([6], [3]). Instead of attaching a billet at the far end of a bar, Kolsky sandwiched a specimen between the two bars. This two bar technique has become the most widely used testing procedure today.

A suchlike model, in Goldsmith's variant [4], is presented in Fig. 2.

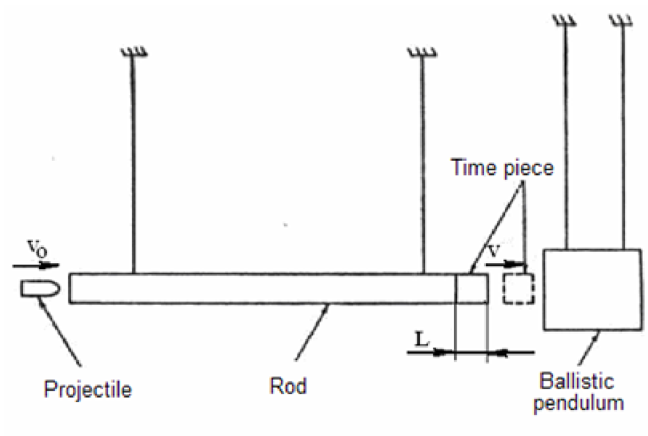

Fig.2. Hopkinson bar experimental setup (wired suspension system)

This device consists of a suspended cylindrical rod, one end of which serves as the impact surface, while the distal face is placed in intimate contact with a shorter bar (time piece), of length *L*. Upon reflection at the free surface, the incident compressive pulse returns as a tensile wave and the time piece will detach itself from the bar when the net pressure at the interface has dropped to zero. The velocity of the time piece can be determined photographically or by means of a ballistic pendulum. Repetition of the experiment with time piece of various lengths permits an approximate delineation of the stress pulse. However, some distortion of the initial signal will occur as the result of dispersive effects in the bar, which may be significant when the pulse length is not too large compared to the diameter of the rod.

During the time, a lot of researchers have studied the propagation of longitudinal waves as a result of bars' collision, using more and more performing Hopkinson devices. Using such a device, properties of materials for high values of deformation can be determined. The measurement device (Kaiser, [6]), is presented in Fig. 3 and it consists of two thin guided bars among which a cylindrical specimen of known length is sandwiched. Hitting the first bar's end with the striker bar, a compressive wave is being generated which will cross the bar toward the specimen. At this place a reflection of the incident wave towards the initial contact end occurs and at the same time a transmission of the wave along both the specimen and the second bar appears, producing a plastic deformation of the specimen. Both reflected and transmitted waves are proportional to the values of deformation and the stress of specimen, which can be used to calculate the material constants.

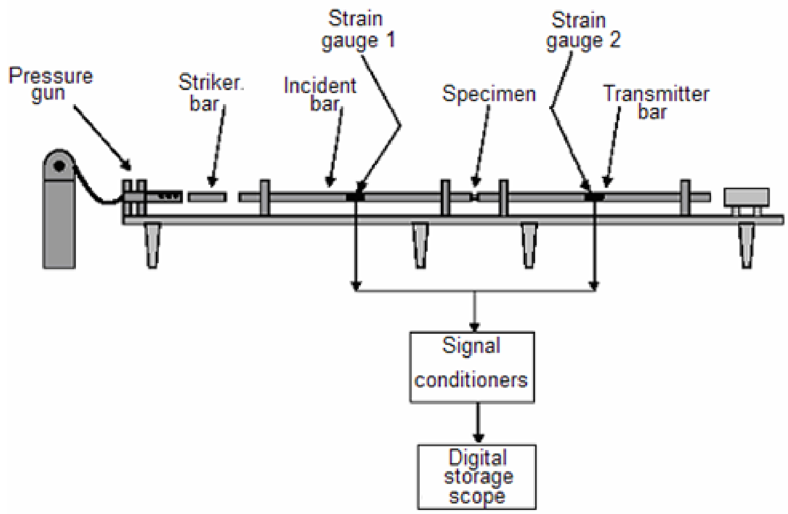

Fig.3. Hopkinson device (guided bars' system)

The constructive solution for guided bars needs perfectly straight, calibrated bars and sophisticated guidance bearings, in order to avoid the contact between the bars and bearings (which would lead to a loss of the wave's energy through bearings)

The short description above is only a revue of the main measurement methods of impact phenomena. It has to be admitted that the assignation of an adequate technique of recording the impacts' effects is quite a difficult problem.

A correct interpretation of the experimental results requires a detailed understanding of the characteristics, the admission of measurement equipment's deficiency and it often needs profound knowledge of the impact phenomena.

3. EXPERIMENTAL DATA CONDITIONING METHODS

Depending on the complexity of the acquired signal, several signal conditioning methods are known. For the case of solid bodies impact resulted signals are usually complex, because of the interference between the impact and the rod's own vibrations generated by the impact. For this reason, beside time range analysis and integral transforms, "wavelet" analysis is used in the acquired signals analysis.

3.1. Integral transforms

The most used method of complex signal decomposition in several simple signals is the Fourier transform. The main element of the Fourier transform is the fact that the signal is decomposed in a series of sine curves. In computer aided data analysis the only transform encountered in references is the Discrete Fourier Transform (DFT). Using DFT the original signal is decomposed in a set of *N/2+1* cosine curves and a set of *N/2+1* sine curves. Each of these curves has a predefined frequency marked *k*, indicating the number of periods which corresponds to the *N* values of the original signal.

Cosine functions amplitudes are symbolized as $\mathrm{Re}\,\overline{X}[k]$, while the sine function amplitudes are $\mathrm{Im}\,\overline{X}[k]$. Fourier synthesis equation (IDFT) is given as follows:

$$x[i]=\sum_{k=0}^{N/2}\mathrm{Re}\,\overline{X}[k]\cos(2\pi ki/N)+\sum_{k=0}^{N/2}\mathrm{Im}\,\overline{X}[k]\sin(2\pi ki/N) \qquad (1)$$

where:

- *x[i]* represents the *i* - th value of the input data set (acquired data)
- *i* represents the input data value index (*i = 0...N-1*)
- *k* is the frequency of the current cosine or sine curve
- *N* represents the number of the data input set sample
- $\mathrm{Re}\,\overline{X}[k]$ is the cosine curve amplitude having the *k* frequency
- $\mathrm{Im}\,\overline{X}[k]$ is the sine curve amplitude having the *k* frequency

In practice the results of the Fourier transform calculus represented by the $\mathrm{Re}\,\overline{X}[k]$ and $\mathrm{Im}\,\overline{X}[k]$ coefficients are used to create spectrograms.

3.2. Wavelet analysis

Wavelet method arises from the Fourier analysis, widely used in signal analysis applications. The main applications regard compression and filtering. A complete description of the wavelet applications is presented in [2].

Fourier analysis is useful in signal processing regarding a lot of applications but this frequency method has the main disadvantage of loosing local information (id est time information in the case of temporal signals).

In 1946, Dennis Gabor adapted the Fourier transform in a time-dependent window analysis. This window can slide across time coordinate, thus obtaining a series of specters which allows an approximation of the local characteristics. This technique was named “Short Fourier Transform” (STFT) or “time-frequency representation”. This method was the basement for researches in texture segmentation using optimal Gabor filters [9]. The main limitation of this kind of transform is the fix dimension of the scanning window.

Wavelet analysis was the next step in the development of the analysis methods which involves techniques similar to variable dimensions of the scanning windows. Wavelet analyses synthesis development is presented in Fig. 4.

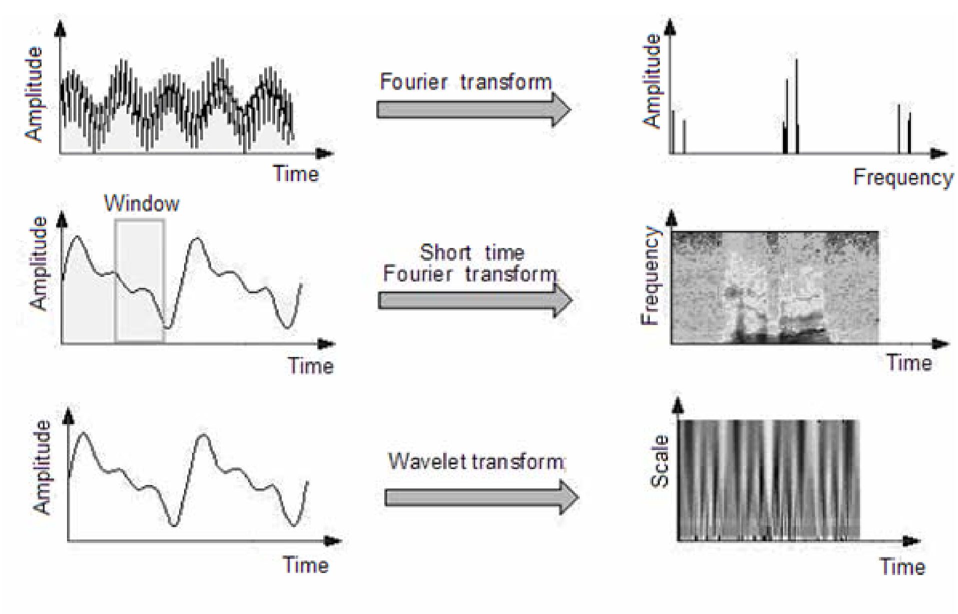

Fig.4. Wavelet analyses synthesis development

It can be noticed that wavelet analysis uses a time-scale type representation instead of a time-frequency type representation.

As it is well-known, the Fourier transform decomposes a signal in different frequency sine curves. Similarly, wavelet transform decomposes a signal in "mother wavelet" and its' "scaled" versions (comprised or extended) and "shifted" versions (or displaced in phase in time range).

In mathematic terms, wavelet transform can be expressed as:

$$C(a,k) = \int_{-\infty}^{\infty} f(t)\psi(a,k)dt \tag{2}$$

where:

C(a,k) –wavelet coefficients;
f(t) – the signal;
ψ –wavelet function;
a – scale;
k – movement in time range.

Wavelet function selection *ψ(a,k)* is extremely important and depends on the application where it is used.

There are a series of established types of wavelet functions, specially used in compression and filtering applications such as: Haar, Daubechies, Meyer BIOR, RBIO. Specialized wavelet function design is the subject for different studies such as sounds and vibrations analysis, surface roughness estimation and characterization using biorthogonal spline wavelet functions or frequency normalized wavelet transform and three-dimensional analysis of surfaces.

Another class of application concentrates on signal filtering and noise removal.

Continuous wavelet transform (CWT) realized for a continuous variation of *a* and *k* is difficult to use so that discrete wavelet transform (DWT) obtained for *a* and *k* values that are powers of 2 is used instead.

DWT is implemented through a very efficient algorithm (offered by Mallat in 1988) named „two-channel subband coder" or „fast wavelet transform".

The basic DWT algorithm consists in the signal filtration (Fig. 5.a) having as the result the wavelet coefficients of the signal approximate (cA), corresponding to the high frequency components. This algorithm can be successively applied (Fig. 5.b) thus obtaining more approximation steps.

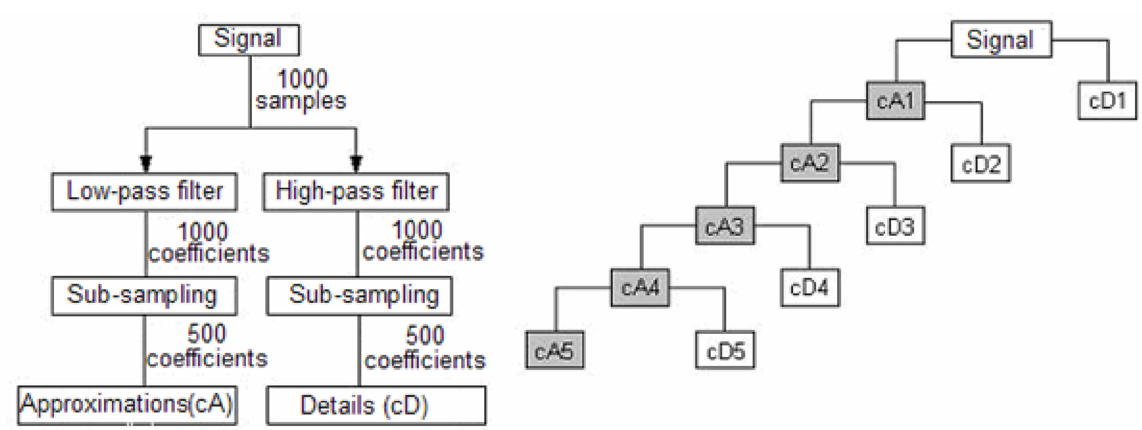

Fig.5. Wavelet implementation schemas:
a) Wavelet transform for one level; b) Multi-level wavelet transform

After filtration a sub-sampling operation is made (eliminating thus every other coefficient) so that finally the numbers of coefficients after transform remains the same as the original signal number of samplings.

4. CONCLUSIONS

The techniques described above were used in the selection process of the experimental stand model used to study the light gauge rods coaxial impact based on the longitudinal wave's propagation theory [5]. Time range, frequency range and scale-frequency range data processing were used in order to relieve the analyzed phenomena.

5. BIBLIOGRAPHY

[1]. Arnold, V., *Mathematical Methods of Classical Mechanics*, 2nd Ed., New York: Springer-Verlag, 1989.
[2]. Davis, G. M., Nosratinia, A., *Wavelet-based Image Coding: An Overview*, www.geoffreydavis.com, 2001
[3]. Field, J.E., Proud, W.G., Walley, S.M., Goldrein, H.T., *Review of experimental techniques for high rate deformation and shock studies* in "New Experimental Methods in Material Dynamics and Impact", ed. W.K. Nowacki and J.R. Klepaczko, publ. Warsaw, Poland, Institute of Fundamental Technological Research: pp. 109-177, 2001
[4]. Goldsmith, W., *Impact. The theory and physical behavior of colliding solids*, Eduard Arnold (Publishers) Ltd, London, 1960
[5]. Hule, V., *Dynamic systems with percussion interactions. Applications in case of long bars,* Doctoral thesis, "Politehnica" University of Timişoara, 2006.
[6]. Kaiser, M. A., Wilson, L. T., Wicks, A. L., *Experimental Techniques in Hopkinson Bar Testing*, American Physical Society, Conference on Shock Compression of Condensed Matter June 28-July 2, 1999 Snowbird, Utah
[7]. Knapp, J., Altmann, E., Niemann, J., Werner, K. D., *Measurement of shock events by means of strain gauges and accelerometers*, Measurement, Volume 24, Number 2, September 1998, pp. 87-96
[8]. Stevenson, M. G., Campbell, J. D., *An optical method for direct measurement of strain in a torsional Hopkinson-bar apparatus*, Journal of Strain Analysis, vol. 10, July 1975, pp. 172-179.
[9]. Tsai, D. M., Wu, S.K., Chen, M.C., *Optimal Gabor filter design for texture segmentation using stochastic optimization, Image and Vision Computing*, Elsevier Science B.V. 2000