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The use of high-speed camera for dynamic crushing registration

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Abstract: *A method of high-speed camera recording for registration of dynamic crushing was presented. Energy-absorbing structures commonly used in the automotive industry were studied. Registered high-speed camera signal was compared with the signal obtained by integration of the crushing force.*

Keywords: *thin-walled structures, crashworthiness, high-speed camera*

1. Introduction

The experimental studies of energy absorbers were conducted. Extra attention was paid on deformation process registered by camera. This research relied on dynamic crushing of top-hat and double-hat elements used commonly in load-carrying structures of cars [1]. Profiles were made of advanced high-strength steel (ASHH) rolled along the direction of deformation (Fig. 1).

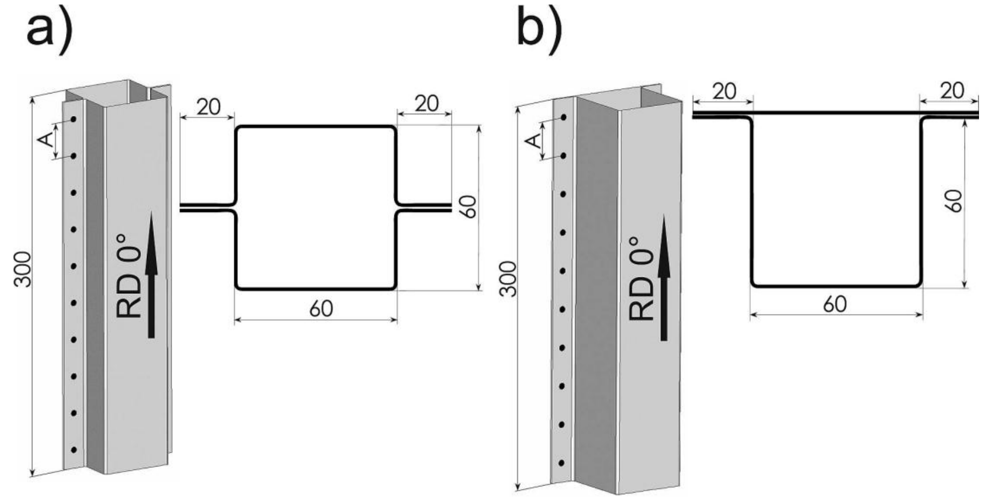

Fig. 1. Examined specimens (RD – Rolling direction)
a) Double-hat b) Top-hat

Dynamic tests were conducted using a gravity drop hammer [2]. It consisted of a frame made of steel. Tup of the hammer was lifted to the desired height using a power winch controlled by operator. Precise positioning was guaranteed by a limit switch mounted at adequate height. Contact of the tup and the limit switch resulted in winch stop. Rope wound on the drum passes through a pulley system. Electromagnet was fixed at the end of the rope. Its switching was done by operator, resulting in release of the hammer tup. Falling elements were guided using the bearings and grease-coated brass rails. Optical gate was installed to the frame at the proper height.

The measurements were started by the intersection of the optical gate beam and falling mass. The use of optical gate guaranteed the time synchronization of all measuring devices (Fig. 2).

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Following elements were used for registration purpose:

- Three force sensors (PCB Piezotronics) with measuring range 50–250 000 N. They were located between the bases: upper and lower. Those two plates were screwed together in three points in order to minimize oscillation of the recorded signal. Measurements were acquired by TEAC recorder connected via Ethernet to a PC with dedicated software installed,
- High-speed Phantom v12 camera allowing to record up to 1 million frames per second at reduced resolution. The camera was connected via an ethernet cable to the PC with dedicated software installed. Process was illuminated by 5 kW special spotlight. Reference point markers were placed on the positioning plate, the upper part of the base, the tup and selected reference point. Dedicated image analysis tool enabled determination of the tup displacement as a function of time. Differentiation of obtained signals allowed to determine the velocity and acceleration of the tup as a function of time [3].

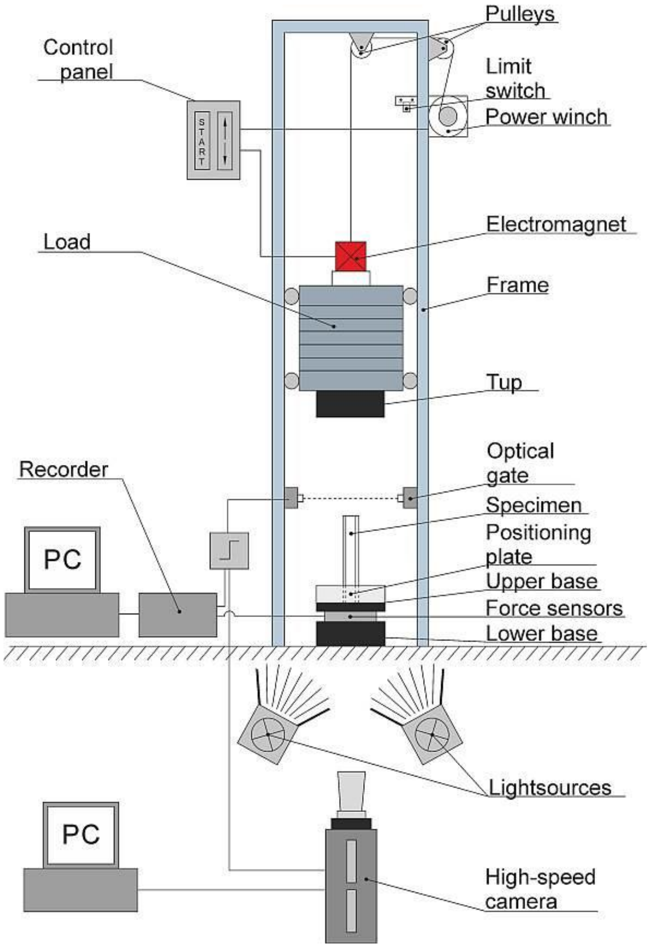

Fig. 2. Scheme of the dynamic crushing test stand [3]

2. Signal correlation

Two analyses of the camera and force sensors signal were made: the displacement and crushing force of the tup as a function of time. The diagram of the force signal (known mass allowed to calculate acceleration level of the tup) after double integration and the signal obtained directly by camera measurement were compared. Analysed signals were consistent (Fig. 3).

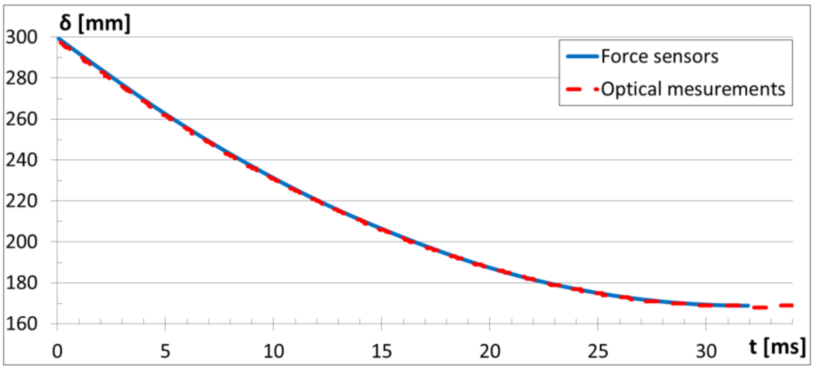

Fig. 3. The displacement of the tup as a function of time

Moreover, the force sensors and camera signals were compared. Camera displacement signals were double differentiated and filtered by both low-pass Channel Frequency Class (CFC) 4-channel Butterworth low-pass filters: CFC140 (cutoff frequency 1400 Hz) and CFC 180 (cutoff frequency 1800 Hz) [4]. Because the weight of tup was measured, it was possible to convert acceleration to force. Analyzed functions were uncorrelated, especially at the beginning. Depending on the selected filter, different shape of the curve was obtained.

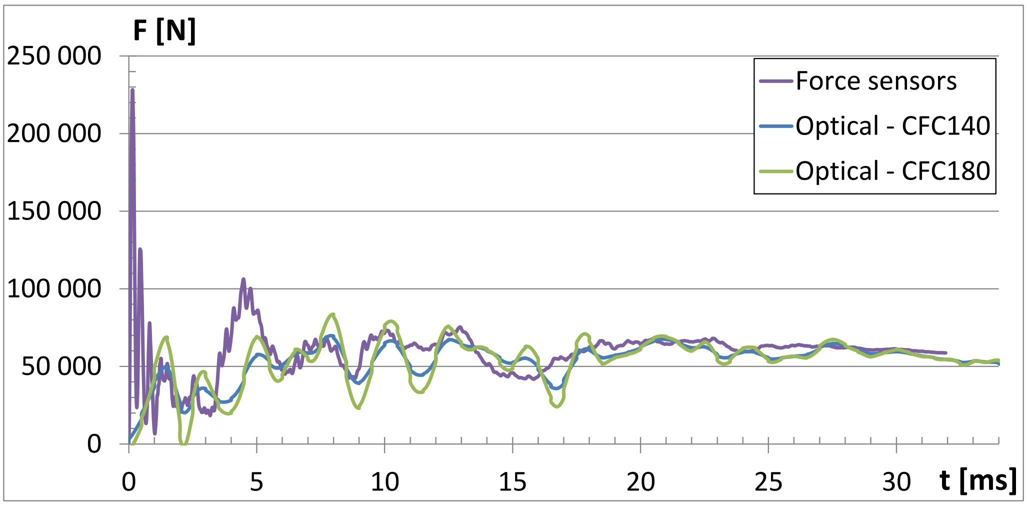

Fig. 4. The force of the tup as a function of time

3. Summary

The study demonstrated the correlation of tup displacement and crushing force function versus time obtained using the methods described. Differentiation of camera signal — without the use of filtering — gives useless and noisy signal. Filtered signals differ depending on the filter cutoff frequency. No correlation was noticed between the force signals obtained by both methods, particularly in the first 10 ms of the process. To create a force versus time diagram, which is the basis for the analysis of energy absorption, two signals should be used: force obtained directly from force sensors, and displacement obtained by high-speed camera. Because the diagram of the force signal after double integration (force sensors) and the displacement signal obtained directly by camera measurement were consistent (Fig. 3) it is also allowable to use only signal from force sensors. The use of only camera signal is highly deprecated because double differentiation gives noisy signal.

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WYKORZYSTANIE SZYBKIEJ KAMERY DO REJESTRACJI DYNAMICZNEGO ZGNIATANIA

W pracy przedstawiono badania dynamicznego zgniatania profili cienkościennych o przekrojach: jednoomegowym (top-hat) i dwuomegowym (double-hat). Badania odbyły się na grawitacyjnym młocie spadowym. Proces deformacji struktury rejestrowany był za pomocą czujników udarowych siły umieszczonych pod podstawą próbki, co przy znanej masie bijaka pozwoliło na wyznaczenie przebiegu jego przyspieszenia. Wykorzystano także szybką kamerę, która pozwalała na bezpośrednie wyznaczenie przemieszczenia bijaka w czasie. Otrzymane sygnały — po ich scałkowaniu, bądź zróżniczkowaniu — zostały ze sobą porównane. W pracy wykazano wzajemną korelację przebiegów przemieszczenia bijaka w funkcji czasu otrzymywanych za pomocą opisanych metod. Różniczkowanie sygnału uzyskanego za pomocą kamery — bez użycia filtrowania — daje wyniki bardzo zaszumione. Sygnały przefiltrowane różnią się między sobą, w zależności od własności filtra. Nie dostrzeżono korelacji pomiędzy sygnałami przyspieszenia uzyskanymi za pomocą obu metod, szczególnie w pierwszych 10 ms procesu.