Acoustically Triggered Ultra-High Speed Camera System for Composites Failure Imaging

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Abstract

High speed imaging has been successfully used to capture the deformation of composite structures allowing analysis of behaviour and failure modes. However, to capture crack propagation and delamination in greater detail, frame acquisition must be pushed to higher and higher speeds. This presents several technical and practical difficulties, primarily stemming from hardware limitations. In this investigation, we report the development of an acoustically triggered high speed camera system and a demonstration of its ability to autonomously capture composite failure at up to 1 million frames per second (fps).

Introduction

High speed imaging has been used for producing strain maps of composite material subject to high strain-rate loading; to identify the point of initiation in ply-debonding in tapered composites; locate crack initiation in functionalised materials; facilitate digital image correlation (DIC) analysis of z-pin displacement, quantify buckling behaviour of sub-laminates in compression after impact (CAI) testing; observe the dynamics of vibrations; and enable failure analysis due to manufacturing defects [1-7]. In most cases, the camera is triggered after the failure event, either via a signal from the test machine indicating an instantaneous drop in load due to failure; or, manually by the user, with the buffered images in the camera memory stored. However, regardless of the system employed, the cameras possess a finite quantity of memory: As frame rates are pushed higher to capture more intricate detail, subsequent recording time diminishes.

Due to the brittle behaviour of composite materials, failure can occur almost instantaneously, with little pre-emptive indication of imminent failure. Since in most cases the time of failure is unknown, an ‘end-trigger’ recording mode is usually employed. Recording is looped until an input signal is received, associated with the last frame of the video, and hence captures the failure process up to that point. Alternatively, a custom trigger point can be used, with a pre-determined number of frames recorded before and after the input signal is detected. However, the delay in signal processing, or human reaction time, can result in the recorded images occurring after the failure event has passed (especially when recording at high fps). Difficulty in capturing failure at high frame rates is compounded by the requirement for intense and, since operating in ‘end-trigger’ mode, continuous illumination and/or aperture settings if a greater depth of field is required.

Some systems (such as the Photron SA-Z unit used in this study) require a reduction in resolution to off-set reduced recording time. Of course, this is only suitable if investigating small samples or the point of interest is known prior to failure, but nevertheless can facilitate conventional or manual triggering, due to the relatively long record times achieved. However, other systems (such as the Kirana unit, also used in this study) have a fixed resolution regardless of frame rate thus allowing a larger field of view, but can only capture a fixed number of frames (180 for the Kirana). At the highest recording rate of 5 million fps, this equates to a recording time of 36 µs, thus precluding conventional triggering methods (Table 1).

	Photron – SA-Z			Specialised Imaging - Kirana		
Aperture	Max Speed (fps)	Resolution	Recording Time (s) [Frames]	Max Speed (fps)	Resolution	Recording Time (ms) [Frames]
f/32	10,000	1024 x 1024	2.184 [21839]	10,000	924 x 768	18 [180]
f/16	50,000	896 x 442	1.132 [57052]	50,000	924 x 768	3.6 [180]
f/8	100,000	640 x 240	1.278 [127801]	100,000	924 x 768	1.8 [180]
f/4	300,000	256 x 128	2.330 [698920]	500,000	924 x 768	0.36 [180]
f/2.8	480,000	256 x 128	2.330 [698920]	1,000,000	924 x 768	0.18 [180]
f/2.8	-	-	-	5,000,000*	924 x 768	0.036 [180]

Table 1. Maximum fps at each lens aperture setting that produces usuable images. As the SA-Z is pushed beyond 100,000 fps, decreased resolution precludes capturing images of the whole specimen. Although recording time of the Kirana is significantly shorter, the fixed resolution allows a larger field of view. *theoretical recording time (awaiting testing).

Acoustic Emission Signal Amplification and Triggering System

In order to record composite failure at high fps, an autonomous triggering system, based upon acoustic emission transducers, is proposed. The acoustical response from the release of energy associated with different failure modes was characterised to aid the selection of an appropriate acoustic emission sensor. A Vallen VS900-M sensor was chosen due to its high sensitivity and broadband response which encompassed the frequency range of the signals detected from different composite materials in different test configurations.

The signal from the acoustic emission (AE) sensor was fed into a two-stage amplification circuit using an Analog Devices OP-42 and a Texas Instruments LM7171 operational amplifier integrated circuit (IC), with the latter providing adjustable gain via a 1 kΩ potentiometer. Both chips offer high-speed amplification for peak detection over a wide frequency range, making them ideal for fast signal processing, thus reducing latency The combination of ICs provided the gain bandwidth product required based on the AE sensor response.

The amplified signal was split to custom peak detector and comparator circuits. The former uses cascading OP-42 amplifiers to charge a resettable capacitor circuit, output to an oscilloscope. This provided an easily interpreted visual signal, corresponding with main failure events. This was used as a reference when setting the threshold signal voltage to trigger the camera, thus minimising premature triggering due to noise and non-catastrophic failure mechanisms (e.g. matrix cracking.) A Texas Instruments LM311 comparator IC was used to compare the amplified signal to the threshold signal (also displayed on the oscilloscope). The output of the comparator was used to (via an inverter IC) feed a monostable multivibrator IC, and in turn create a 100 ns 5 V pulse to trigger the camera itself. The images captured from the acoustic triggering of the Kirana system of a notched composite sample failing in tension are shown in figure 1.

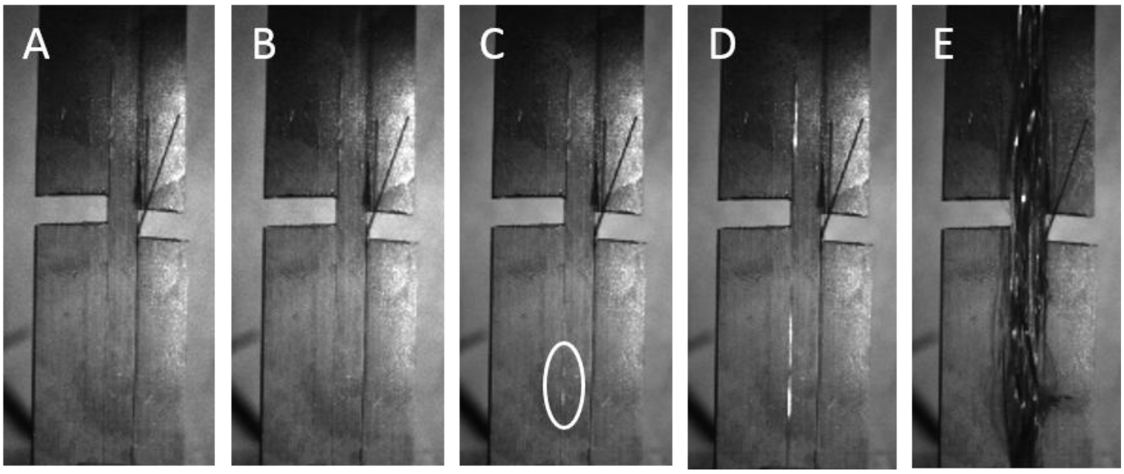

Fig. 1 Failure of a unidirectional carbon-fibre laminate in tension. Kirana triggered autonomously via acoustic system (500,000 fps). (A) 2 μs before trigger. No evidence of premature triggering. (B) 0 μs after trigger. (C) 2 μs after trigger. First evidence of fibre failure (highlighted area). (D) 12 μs after trigger. (E) 192 μs after trigger.

Conclusion

A prototype system that uses the acoustic signal generated from the energy released during composite failure has successfully been developed to trigger a high speed camera. The speed of signal capture and processing allows recording at frame rates which precludes conventional triggering methods, thus revealing greater detail during the failure process.

References

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