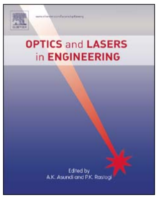
ARTICLE IN PRESS

Optics and Lasers in Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng



Multichannel fiber laser Doppler vibrometer studies of low momentum and hypervelocity impacts

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ARTICLE INFO

Keywords:
Impacts
Vibration
Laser Doppler
Heterodyne
Light gas gun

ABSTRACT

A multichannel optical fiber laser Doppler vibrometer was demonstrated with the capability of making simultaneous non-contact measurements of impacts at 3 different locations. Two sets of measurements were performed, firstly using small ball bearings (1 mm–5.5 mm) falling under gravity and secondly using small projectiles (1 mm) fired from an extremely high velocity light gas gun (LGG) with speeds in the range 1 km/s–8 km/s. Determination of impact damage is important for industries such as aerospace, military and rail, where the effect of an impact on the structure can result in a major structural damage. To our knowledge the research reported here demonstrates the first trials of a multichannel fiber laser Doppler vibrometer being used to detect hypervelocity impacts.

1. Introduction

Impacts can be expected to occur during the lifetime of structures, for example impacts on aircraft due to shrapnel and other airborne particles. Hence the determination of impact damage is important for industries such as passenger aircraft manufactures and their operating companies. Different tests are used to simulate various types of impact: drop-weight tests simulate low-velocity impacts; air-gun systems, in which a small projectile is propelled at high speeds, simulate the type of impacts encountered during aircraft service (e.g. during takeoffs and landings) [1]. To generate extreme velocities (hypervelocity) such as those experienced by spacecraft a light gas gun is required, for example to simulate micrometeoroid impacts and checking shielding and tether arrangements.

Currently, the Light Gas Gun (LGG) at the University of Kent uses Polyvinylidene fluoride (PVDF) probes to monitor the tests and development of damage induced during impacts. These probes are mounted on the edge of the target loading it mechanically and affecting the dynamics of the impact [2,3]. In some cases PVDF probes are not compatible with the specific experimental requirements (e.g. tests on hot targets).

Previously we performed experiments with fiber Bragg gratings (FBG) inside the LGG. The gratings were mounted under tension on the target and interrogated as optical strain gauges. We reported the use of FBGs to measure impacts caused by small projectiles fired from the LGG [4]. This approach was shown to be very effective in comparison with the PVDF transducers [5–7]. This is because the FBG could be bonded much closer to the impact point of the projectile on the target thus providing more precise data on the dynamics of the impact [4]. Despite the good results there are problems with the displacement resolution (1.24 μm) and requirement for the FBG to be mounted with a known strain. Moreover, the sensors cannot be readily removed from the target due to the strong adhesives used.

Target mounted probes can be damaged by the impact even when it is not directly hit by the hypervelocity particle. This is a significant problem when the probe is bonded to the target as is the case with both, PVDF probes and FBG sensors. Another problem with any contact sensor is that it has to be calibrated when installed on the target. The multichannel fiber laser Doppler vibrometer (MFLDV) subject of this paper does not suffer from any of these problems as there is no physical contact between the sensor and the probe and, equally important, the measurements are absolute. The system is ideally suited for complex impact tests such as those with ice or salt projectiles, which demand multiple channel simultaneous sensing.

We adopted the MFLDV previously described in [8] with miniature variable focus collimator probes inside the LGG to analyze the effects of impacts. The main advantages are that the measurements are non-contact, 1 nm displacement resolution is achievable, and the carrier frequency can be optimally selectable for digital processing. Both the amplitude variations generated by the impacts at different target locations and the relative phases between the channels can be determined. This data can be used in modelling the target dynamics.

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http://dx.doi.org/10.1016/j.optlaseng.2017.03.002
Received 27 April 2016; Received in revised form 10 February 2017; Accepted 7 March 2017

Please cite this article as: Posada-Roman, J.E., Optics and Lasers in Engineering (2017), http://dx.doi.org/10.1016/j.optlaseng.2017.03.002

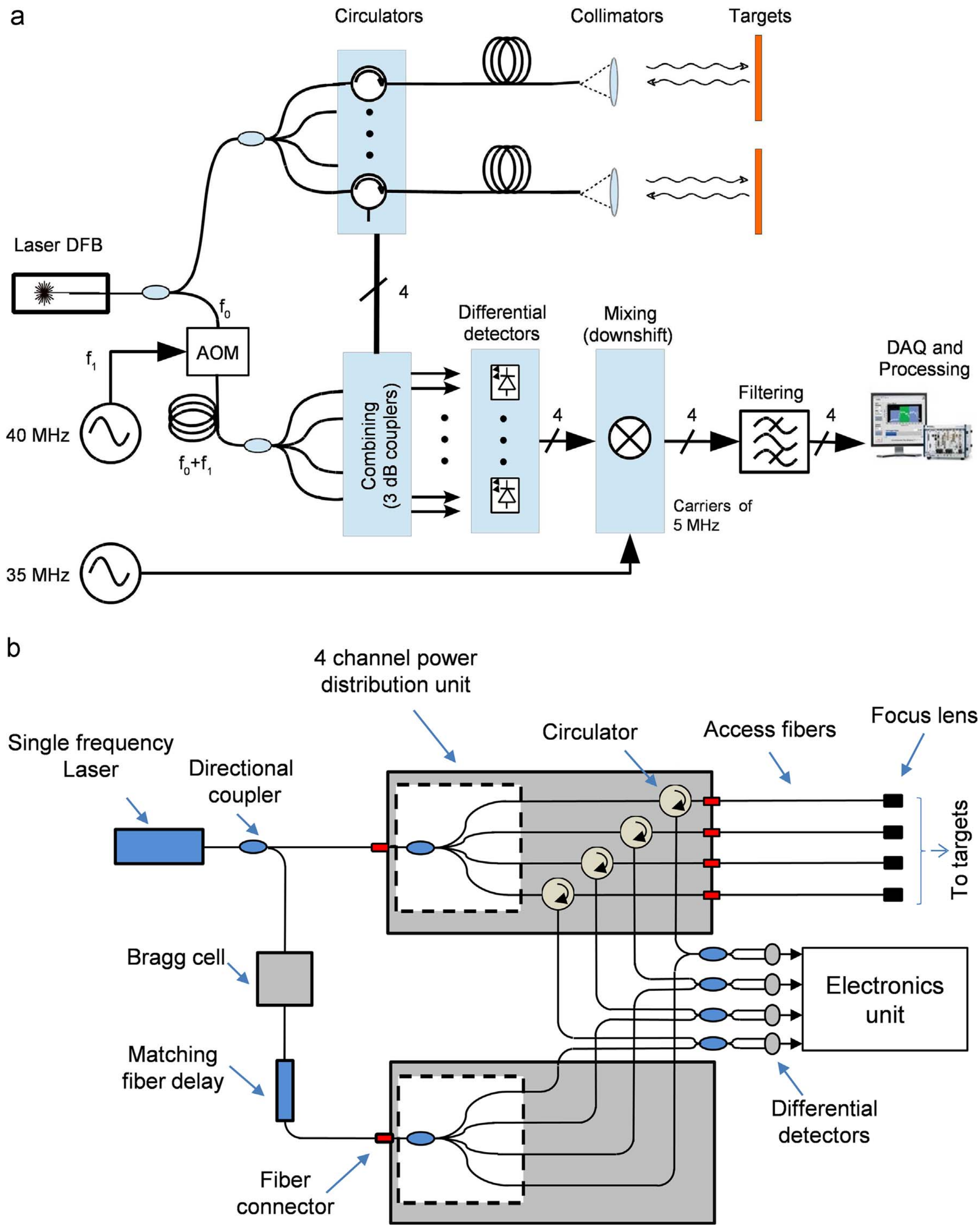

Fig. 1. Multichannel fiber laser Doppler vibrometer (MFLDV); (a) Schematic of the complete system; (b) Optical arrangement of 4 channels (3 channels were used for the experiments reported below).

To enhance the recovered signal amplitude a 1 mm diameter self-adhesive 3Ms reflective paper (effectively weightless) was positioned at each target location. A similar system for general use is reported in reference [9] which has a different topology to that described in Section 2 as it has two acousto-optic modulators (AOM), one a frequency shifter for the Doppler effect, the other a free spaced AOM which injects 4 differentially shifted beams into the transceiver links. Only one detector is required, but the experiments reported were relatively low speed impacts.

2. Four channel heterodyne MFLDV

Fig. 1 shows the MFLDV: the schematic of the complete system (Fig. 1a) and the optical arrangement of 4 channels (Fig. 1b), which is reported in detail in [8]. It contains two 1–4 channel power distribution units (Fig. 1b). Light from a single frequency 1550 nm laser diode is transferred to two paths by a 3 dB directional coupler. The light on one of the paths propagates to the targets via 4 circulators and hence to 4 variable focus collimators where the back reflected signals are transferred to the inputs of four 3 dB couplers. The optical power per