Laser Speckle Reduction based on electroactive polymers

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Abstract: *Optotune has developed an Electroactive Polymer Actuator-based solution to move a diffuser and drastically reduce the speckle contrast of Laser beams: the LSR-5-17 (Laser Speckle Reducer). With its integrated miniaturized electronics for HV generation and motion control, the LSR-5-17 provides a compact 27 x 21 x 6mm solution with a simple 5V micro USB interface for power supply. A miniaturized version of the LSR with an overall size of 9.8 x 6.3 x 1.1 mm3 (without electronics) was also developed and paves the way for the development of miniaturized handheld picoprojectors.*

1. Introduction

Lasers provide numerous advantages over other light sources. For example, the low divergence allows precise control of very high optical power, thus making lasers particularly attractive for projection systems. Laser projection systems have both a broader color spectrum and the advantage that the image is "focus-free". However, lasers do have the inherent problem of speckle. On rough optical surfaces, local interferences occur that manifest themselves as a grainy pattern of spots. This effect causes noise in projected images and reduces the resolution of measurement systems.

There are various methods of tackling the problem of speckle. Rotating diffusers destroy the temporal and spatial coherence of the laser and smear the speckle pattern. However, the requisite mechanics behind this principle limit miniaturization and are susceptible to faults due to the constant friction. A similar effect can be achieved by oscillating mirrors back and forth in the micrometer range, with the caveats that this reflective method is not particularly compact, is dependent on polarization and is normally less effective. Alternatively, laser light can be passed through a vibrating glass fiber, although the practical implementation of this solution in small projectors is understandably not straightforward. A mechanically stable and compact solution can be realized using broadband lasers. However, one of the most important arguments in favor of lasers, namely the high specific brightness, is lost.

Another method would be to vibrate the object or the screen, but again, in most applications this is not feasible.

2. Functional principle

The Laser Speckle Reduce (LSR) (Fig. 1) from Optotune functions in a similar way to a rotating diffuser, but is many times more compact and economical.

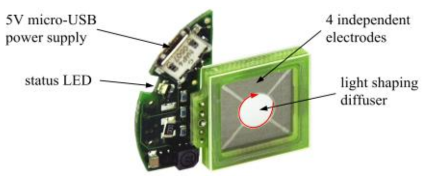

Fig. 1, Optotune's laser speckle reducer: LSR-5-17

The principle is simple – a diffuser is mounted on an elastic membrane and moved back and forth using electroactive polymers. For each discrete position of the diffuser, a different speckle pattern is generated. During the integration time of the detector (~60ms for the human eye), the superposition of patterns lead to a homogenization of the light intensity.

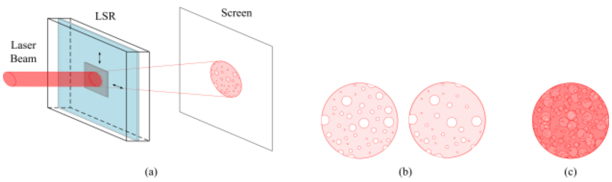

Fig. 2, (a) Functional principle of the trans-missive LSR: (a) discrete speckle patterns, (c) superposition of patterns.

With the correct electrode geometry and appropriate actuation, planar circular oscillation of the diffuser can be generated, with lateral deflections of 100 to 600µm at frequencies of 150 to 800Hz, depending on the size.

2.1 Electroactive polymer

The secret behind the solution is actuators made of electroactive polymers (EAPs, also known as artificial muscles [1, 2]). Flexible electrically conductive surfaces are attached to the top and bottom of a thin elastomer film. When a voltage is applied between the two electrodes, these are charged according to the principle of a plate capacitor, attract one another and thus squeeze the elastic film. (Fig. 3)

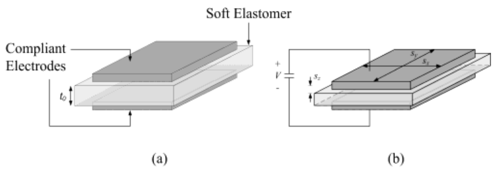

Fig. 3, EAP actuator with (a) no voltage applied and (b) voltage V applied between the two compliant electrodes.

Given that the volume remains constant, the electrodes expand laterally, theoretically by up to 40 percent, and thus move the diffuser.

3. Performance

The maximum speckle reduction that can be achieved depends on the entire optical system. Largest reduction occurs at high oscillation frequencies, large oscillation amplitudes, high resolution diffuser patterns and long observer integration times. As with all methods based on diffusers, an increase in the divergence of the laser beam must be tolerated, this increase being all the more significant with very fine diffuser structures. The optical design may then need to incorporate additional optics to collimate the laser.

3.1 EAP actuator

The amplitude of the motion of the diffuser induced by the EAP actuator depends on the applied electrical field and the frequency of the driving electronic.

The amplitude of the electrical field positively correlates with the lateral expansion of each electrode. Thus, the applied electrical field can be increased up to a certain breakdown limit to enlarge the diameter of the diffusers circular motion.

Studying the influence of the frequency on the LSR shows a typical behavior of a mechanical bead-spring model. The maximum amplitude of the circular motion can be achieved at the systems mechanical resonance frequency, which depends on the geometrical dimensions and material properties of the actuator.

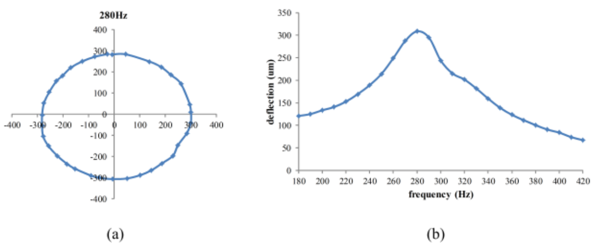

Fig. 4, Typical measurements of (a) the amplitude and (b) the frequency response of diffusers motion.

3.2 Diffuser structures

The standard diffusers used in the LSR have a randomized surface relief structure that relates to the desired divergence angle. The smaller the lateral structure size of the diffuser surface, the larger the divergence angle of the laser beam. The speckle reduction performance of the LSR increases with decreasing diffuser surface structure size, because the smaller the grain-size, the higher the number of totally uncorrelated pictures within a certain motion of the diffuser.

3.3 Speckle reduction

As mentioned in the text below, the speckle reduction performance is influenced by several mechanical and optical parameters of the laser speckle reducer.

The absolute speckle contrast value depends on the entire optics of the measurement system [3]. Due to that, to characterize the speckle reduction of the LSR, the speckle contrast of the pure laser spot, the non-operating LSR and the operating LSR can be compared.

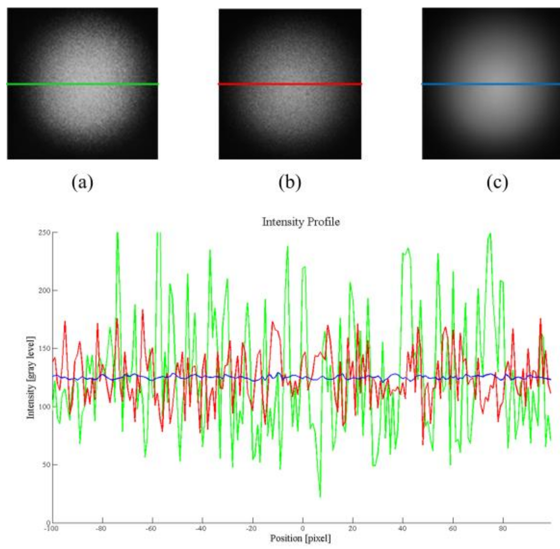

Fig. 5, Typical images of the speckle contrast measured (a) without LSR in the collimated laser path, (b) with the LSR in a static mode and (c) with the LSR in a dynamic mode. The colored lines show the cut planes that refer to the intensity profiles.

The measurement depicted in Fig. 5 with the LSR-5-17-20 (280Hz oscillation frequency, 600µm amplitude, 20° diffuser with ~9um structure size, 10ms integration time) shows a remaining speckle contrast of less than 2%.

4. Conclusion

The principle of electroactive polymers has been around for several decades, but so far the technology has hardly been exploited commercially. With the development of the LSR, Optotune has succeeded in utilizing the advantages of this actuator technology in a specialized optical component that is set to enable key advances in laser projection systems. The extremely compact design (with integrated driving electronic), very long operating life-time, wide temperature range usage and low power consumption are the main advantages of the EAP-base actuation technology.

References

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[2] Y. Bar-Cohen, editor. "Electroactive polymer (EAP) actuators as artificial muscles". SPIE press, 2nd edition (2004).

[3] J.W. Goodman, *Speckle phenomena in optics: theory and applications* (Roberts & Company, Englewood, Colorado, 2007).