Speckle reduction with reluctance force-based oscillating diffusors

D. Stadler, M. Suter, M. Ventura, D. Niederer
Optotune Switzerland AG, Bernstrasse 388, 8953 Dietikon, Switzerland, Phone +41 58 856 30 00, info@optotune.com

Abstract: *Optotune presents a new generation of compact laser speckle reducers based on reluctance force actuators. Using not more than a steel frame, an actuating and a sensing coil, the reliable actuator allows for linear oscillation of heavy glass diffusers at large amplitudes and high frequencies (350 mg, 1000 μm and 130 Hz in the case of the LSR-4C with 17x17 mm clear aperture).*

1. Introduction

Lasers provide numerous advantages compared to other light sources such as low divergence, broader color spectrum and higher lifetime. However, lasers do have the inherent problem of speckle. On rough optical surfaces, e.g. a wall or a cinema screen, local interferences occur which are observed as a grainy pattern of spots by for example a camera or the human eye. This effect causes noise in projected images [1, 2] and reduces the resolution in laser-based measurement systems such as laser triangulation.

Increasing angle diversity of incident light rays is one of the simplest and most effective ways to reduce speckle contrast. A common way to increase angle diversity is to use rotating diffusers such as spinning disks. The rotation represents an effectively one-dimensional motion, limiting the variety of scattering centers per area. In 2011, Optotune introduced laser speckle reducers (LSR) with two-dimensional circular moving diffusers based on electroactive polymer actuators [3-5]. This approach allows for a much larger variety of scattering centers and results in compact form factor (as small as 6 x 9 x 1 mm^3), low weight (< 1 g) and the absence of vibration and audible noise. Two limitations are the high voltage (300 V) required for the electrostatic actuators and a performance drop for diffusers of over 100 mg in weight.

In this paper Optotune presents a new generation of LSRs based on reluctance force actuators which overcomes the two aforementioned limitations.

2. Reluctance Force Actuator

The reluctance force is a result of energy minimization of a magnetic field penetrating in regions with different magnetic permeability, typically air and metal. Considering the simple geometry in Fig. 1, the magnitude of the force is given by

$$F_R = \frac{1}{2}\mu_0 A \frac{I^2 N^2}{d^2}$$

where μ_0 is the vacuum permeability, A the area of the pole face, I the current in the coil, N the winding numbers of the coil and d the length of the air gap. Due to the quadratic scaling, very high forces are realized for increased current or small air gaps, without involving heavy permanent magnets. In order to cause the armature to oscillate, a pulsed current signal is applied. The restoring force is realized by a mechanical spring in such a way that the resulting oscillation direction is as shown in Fig. 3 a).

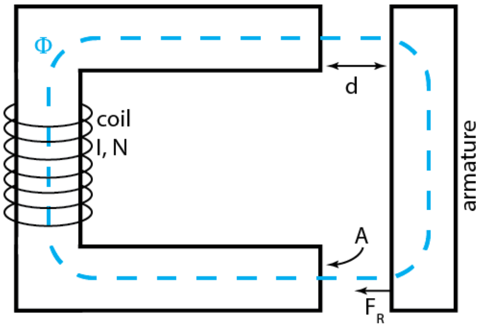

Fig. 1. Reluctance force F_R between two metallic parts separated by a small air gap of length d. The magnetic flux Φ is generated by the electrical I current in the coil.

The advantage of such an oscillator is its relatively high Q-factor, meaning that friction forces and hence energy losses are small.

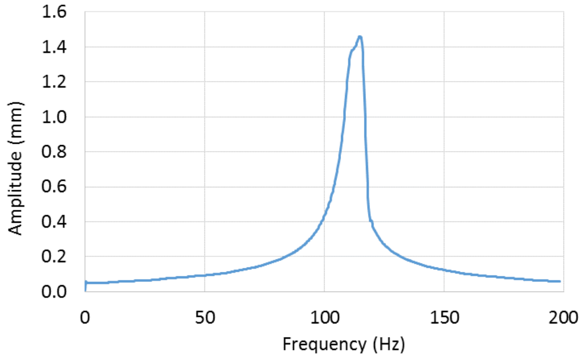

Fig. 2. Measured amplitude of the LSR-4C in relation to frequency showing a resonance peak at around 120 Hz.

A higher Q-factor implies a narrow resonance peak of the oscillator. This poses considerable challenges on how operation is maintained on or close to the resonance peak. A secondary coil is used to measure the electromagnetic induction, which is related to the amplitude. The signal is then maximized in a closed-loop control algorithm. A further benefit of the sensing scheme is to provide an “on”-signal as soon as the oscillation amplitude exceeds a certain threshold.

4. Laser Speckle Reducer Platforms

Based on the technology described above, Optotune presents three platforms for laser speckle reduction in diverse applications:

Platform	LSR-4C	LSR-4T	LSR-4L.
Diffuser [mm^2]	20x20	15x15	6.5x4.7
Size [mm^3]	39x39x5	34x34x5	7x14x2
Amplitude [um]	1000	800	500
Frequency [Hz]	130	150	400
Application	Cinema	TV	Line laser

For best speckle reduction, we propose the combination of two oscillating diffusers (the second be rotated by 90°), realizing an effectively two-dimensional motion. Using the same diffuser angle for both diffusers provides the best trade-off between high speckle reduction and minimal increase of divergence.

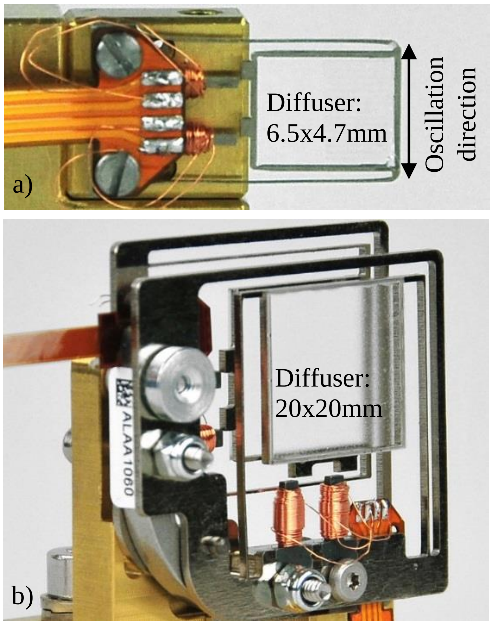

Fig. 3. Photographs of a) the LSR-4L and b) LSR-4C. The LSR-4L oscillates linearly along the vertical direction. The LSR-4C realized a two-dimensional motion by combining two oscillating diffusors rotated by 90°.

Fig. 3 shows that the LSR comprises only a small number of parts which significantly reduces the complexity of the product. Due to the compact design, high oscillation frequencies are possible. The controlled amplitude prevents material fatigue and guarantees long lifetime. Large diffusers produce considerable vibration which have to be handled by rigid mounting to large masses.

4. Laser display application

One application that benefits largely from speckle reduction is laser projection since any speckle strongly degrades the projected image quality. In Fig. 4, a generic optical setup including the LSR is presented in which strong speckle reduction is achieved. The LSR is positioned in (or close to) the focal point of an axicon lens, right before a beam homogenizer (an integrator rod, light pipe or fly’s-eye MLA). The benefit of the axicon is that it creates a more homogeneous angle distribution incident on the LSR. In order maintain high optical efficiency the exit angle after the LSR should be less than the acceptance angle of the homogenizer.

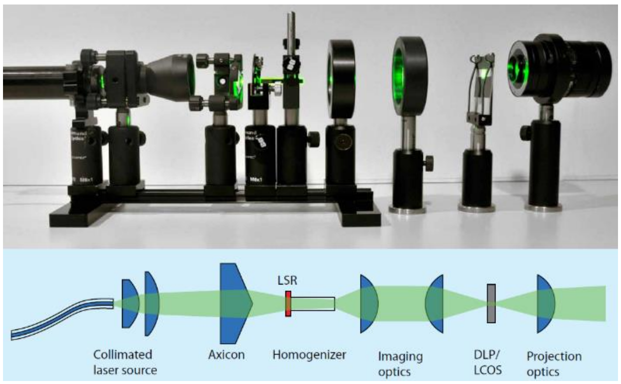

Fig. 4. Optical layout for speckle-free laser projection. The collimated laser beam from an optical fiber is focused by the axicon lens. The LSR is positioned close to the focal point of the axicon. The de-speckled beam obtains a uniform flat top profile by propagating through the beam homogenizer. To complete the projection setup, a DLP/LCOS device and projection optics is needed.

The result is a speckle-free and homogeneous beam. In combination with a DLP/LCOS device and specific projection optics, speckle-free laser projection is realized, as shown in Fig. 5.

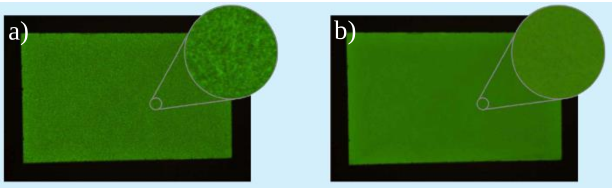

Fig. 5. Speckle reduction in a projection system. Image a) shows the speckle pattern that appears when the LSR is turned off. In image b) the LSR is turned on and significantly reduces the speckle effect.

5. Conclusions

A new generation of reluctance force-based laser speckle reducers is presented, which enables effective speckle reduction in a variety of applications including cinema, TV, desktop- and pico-projectors as well as line lasers. The main advantages are the very compact form factor, high reliability and long lifetime as well as low power consumption.

References

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