Illumination for a Laser Profilometry System Targeting Fast Moving Objects

C. Gimkiewicz, F. Kaess

Laser profilometry is suitable for in-situ measurements of fast moving objects as required by many applications of robotics and automation, mobile vehicles as well as in the field of transportation and autonomous circulation. Accurate measurements of items moving at very high speed are necessary for the observation and control of positioning tasks, abrasion processes, or pressure induced profile changes, for example to ensure safety and quality in a cost-effective way. The presented illumination method for a laser profilometry system allows the measurement of a profile precision in the order of 0.1 mm at speeds up to 100 km/h.

Laser profilometry is a contactless technique to measure the relief of a distant surface. It makes use of a projected laser pattern onto the target object. The deformation of the known laser pattern allows to evaluate the objects surface profile by triangulation. In order to capture object features within the pixel resolution of the camera, the time of image acquisition is short. For example, the desired resolution is in the order of 0.1 mm, meaning that an object detail of a size of 1 mm should be imaged onto 10 pixels. For a speed of 100 km/h (27778 mm/s), the sensor shutter speed and/or the illumination time has to be shorter than 3.6 μs. The object reflectivity in most cases is very low, since the surface of interest is not a mirror but has scattering and absorbing properties. Experiments for a field of view of around 200 mm and an object distance of around 400 mm have shown that the laser power has to be in the order of several Watts and focused to a line width of less than 1 mm to achieve profile accuracies in the order of 0.1 mm in real world conditions (e.g. sunlight). However, increasing the laser power increases the minimum feature size of the laser pattern so that profile features are less resolved, since high-power lasers come with larger beam diameters. This is especially true when limitations on robustness, size and handling demand a connection of the laser light to the measurement set-up via an optical fiber: In this case, a small fiber core is not capable to endure high laser power on the long term. A laser beam coupled into a single mode fiber, for example, offers a maximum power of around 100 mW, a multimode laser however can offer up to 4 W when coupled into a multimode fiber with a 50 μm core size, and up to 8 W for a 100 μm multimode fiber.

Typical laser line-generating optics are based on a single lens design to be compatible with a compact and cost effective product. Typical line width is <1 mm and the line-generating optics are designed for single mode lasers or single mode fibers. Here, we present an optic that is designed for multimode lasers and generates one or multiple laser lines with off-the-shelf components. We have employed cylindrical lenses. As a consequence the beam shaping in the xz-plane (with the z coordinate as the beam direction) is nearly independent of the optical functions in the yz-plane. Only the length of these "line-spreading-beam-path" in the xz-plane (Figure 1) has to be adapted to the length of the "line-focusing-beam-path" in the yz-plane.

In order to generate multiple lines, a diffraction grating can be placed at the output surface of the laser line-generator.

The "line-spreading-beam-path" consists of a collimating cylindrical lens and a line-generating lens, i.e. a Powell like a sphere [1], which is in principle a combination of an axicon and a short focal length lens. Such line-generating lenses are designed to achieve a homogeneous power distribution along the laser line. However, in a profilometry system with a camera, a flat top power distribution might not be the optimum, since usually the imaging optics of the camera transfers less power from the edges of the field of view than from the center. (The effect is known as "Cosine Fourth" law and describes the falloff of the illuminance across a camera image.) A homogenous illuminated laser line would appear darker at the image edges on the camera's sensor. The advantage of our design is that it allows to counterbalance the falloff: By changing the position of the collimation lens, different power distributions can be achieved and the mentioned relative darkening of the image toward its borders can be compensated.

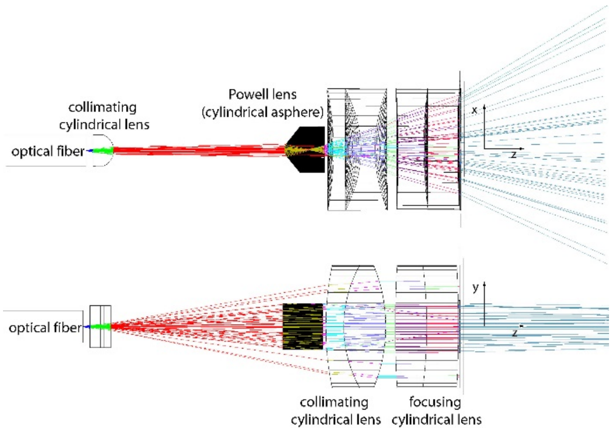

Figure 1: Scheme of the laser line-generator optics. The upper image illustrates the "line-spreading-beam-path" as a scheme in the xz-plane, the lower image shows the line-focusing-beam-path" as a scheme in the yz-plane.

In our current design with an object distance of 400 mm, the size of the optics is 70 mm in length, excluding the fiber connector, and 25 mm in diameter; the large diameter is necessary to reduce the effect of the diffraction on the laser line width. We have calculated a total line focus size of FWHM = 0.35 mm for a 50 micron fiber output and FWHM = 0.75 mm for a 100 micron fiber. With this optical design, a profile resolution of less than 0.1 mm can be achieved with a 4 W laser coupled to a 50 micron fiber in real world conditions.

---

[1] I. Powell, "Linear diverging lens", Patent No. US4826299 A (1989).