A LASER MICROPROJECTOR NON-DESTRUCTIVE CONTROL METHOD FOR SURFACE CRACKS

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A laser microprojector method is introduced within the non-destructive visual inspection methods for surface testing. A contracted and collimated laser beam is projected onto a surface to be inspected, and its reflection expanded, projected onto a screen and examined. The surfaces of the used wood-machining tools are used for light reflection, rendering examples of unhomogeneous structures with the only regularities corresponding to light diffraction on the traces of the tool wear.

INTRODUCTION

Among other methods of non-destructive testing, detection of surface micro-cracks plays an important role as proved by the extent of application of e.g. inspection by penetrants. An alternative is offered by the application of the laser light. This light is known to be highly coherent, and its strictly parallel beam (once it is achieved) can be used to scan the surfaces to be inspected. The high light intensity within the beam provides a sufficient intensity of the light reflected from most metallic surfaces, their features clearly showing within the reflected beam.

The only practical problems are related with achieving the beam collimation, since contrary to the popular belief, the exit beam from a laser is a divergent one due to the diffraction at its exit aperture (e.g. Detlaf and Yavorskiy (1)). This problem has been successfully solved by the lens system of the laser microprojector (Todorovic et al. (2)). The system also

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provides the expansion of the reflected light beam, thereby allowing its essential features to be seen more clearly. The poorer reflectivity of some surfaces can be made for by application of higher power output lasers, allowing the method to be applied in all but the poorest reflectivity cases.

EXPERIMENTAL

An adjustable laser beam collimator is operated in a manner opposite to that required for an expanded and collimated laser beam (Todorovic et al. (3)) to be produced. The geometry of the optical system is shown in Fig.1 (not to scale).

An initially divergent laser beam (the beam divergence angle 2 θ_d being determined by diffraction at the laser exit aperture (1)) is passed through a converging lens L_s placed at a distance z_s from the laser exit, i.e. at the distance $p = z_e + z_s$ from the equivalent point source of the laser beam (Todorovic (4)). The image of the point source would have been formed at a distance l, determined by the lens equation for the lens L_s of the focal length f_s, but for the introduction of the diverging lens L_r. The placement of the latter at a distance $|f_r|$, equal to the absolute value of its focal length in front of this image, changes the convergent beam originating at the converging lens L_s into a stritly parallel and collimated one from the lens L_r onwards. Application of simple rearrangements, based upon clear geometrical relationships, to the mentioned lens equation for the relationship between the distances of the point source and its image and the focal length, gives the expression for the contracted and collimated beam diameter in the form

$$d_r = 2\ |f_r|\ [(z_e + z_s - f_s)\ \mathrm{tg}\ \theta_d]\ /\ f_s$$

and for the lens separation distance a in the form

$$a = [(z_e + z_s)\ f_s\ /\ (z_e + z_s - f_s)] - |f_r|$$

For the given laser and lenses, it is the distance z_s which will determine the beam diameter, the inter-lens separation distance being dictated by its chosen value and the necessary beam collimation condition.

The collimated beam is thereafter brought onto the surface to be examined. Following its reflection from the surface, it is brought to the beam expanding lens system (Fig.2) and presented on the screen. At the focal length distance f_{se} from the expanding lens L_{se}, the former parallel beam converges to its diffraction-limited waist value w_0 (shown in Fig.1 and discussed elsewhere (4)). It diverges thereafter to the screen image diameter value d_e, determined by the collimated beam diameter d_r, the distance l_e between the screen and the focus of the lens L_{se}, and the focal length of the latter by the simple relationship

$$d_e = d_r\, l_e / f_{se}$$

The linear optical enlargement d_e / d_r therefore applies also to any detail within the beam, determined only by the screen-to-focus distance to focal length ratio, l_e / f_{se}, and the necessary illumination at the screen having been achieved with a given laser.

Once displayed on the screen, the reflected beam can be recorded photographically or generally analyzed in any other suitable manner. From the features shown on it, the presence of microcracks and their size can be established. This is possible since within an either homogeneously illuminated area in the cases of high reflectivity, or irregularly illuminated ones for unhomogeneous and not much polished surfaces, regular diffraction patterns correspond to the presence of scratches or microcracks within the area illuminated by the laser beam.

The Results of Experiments

For a 2 mW CW output He-Ne laser, its beam characteristics (beam divergence angle $2\ \theta_d = 1.6$ mrad, equivalent point source distance $z_e = 964$ mm and beam waist radius $w_0 = 0.36$ mm) have been determined experimentally. With the former and the lenses: L_s, L_r and L_{se} of the focal lengths $f_s = 40.5$ cm, $f_r = -35$ cm and $f_{se} = 2.5$ cm, respectively, the contracted collimated beam diameter $d_r = 3$ mm has been achieved for the values of the distances $z_s = 167.5$ cm and consequently $a = 15$ cm. The screen-to-focus distance has been set at a value $l_e = 425$ cm, resulting in the linear optical enlargement value $d_e / d_r = 170$.

This being just the experimental verification of a method to be newly introduced, only the visible scratches on the worn wood machining tools were inspected. Among the irregular forms corresponding to surface structure unhomogeneities, the regular patterns of recurrent light intensity maxima indicated the presence of diffraction on crack edges. The values found for a set of bandsaws ranged from 0.3 mm for clearly visible macroscopic longitudinal traces of tool wear down to 0.09 mm for those barely visible by the naked eye, the important advantage of the method being apparent in the properties of the Fraunhofer diffraction pattern. They result from the relationship between the size of the object, e.g. the crack width d and the wavelength of the illuminating light, λ, in the form (1)

$$\sin \theta_z = z \lambda / d$$

where z is the order of the diffraction light intensity maximum, and θ_z is its angle of deviation from the original direction of the beam (and also of the diffraction maximum of the zero order). Therefore the larger angular deviations would appear for smaller size cracks, making the diffraction patterns more easily recognizable.

CONCLUSIONS

The applicability of the laser microprojector method for surface crack inspection has been tested in the case of visible damages of the surface structure of the worn wood machining tools. On the basis of the established effects of diffraction, the extention seems feasible of the method also in the region of lower crack width values, the limitations being set by the joint effects of illumination and light reflectivity of the examined surfaces (a decrease of the latter requiring an increase of the former and vice versa).

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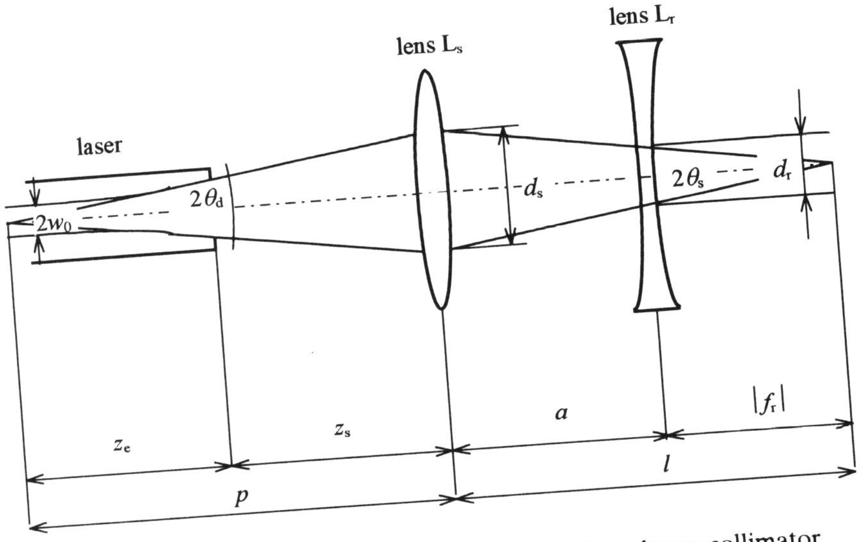

Fig.1- Schematic representation of the adjustable laser beam collimator

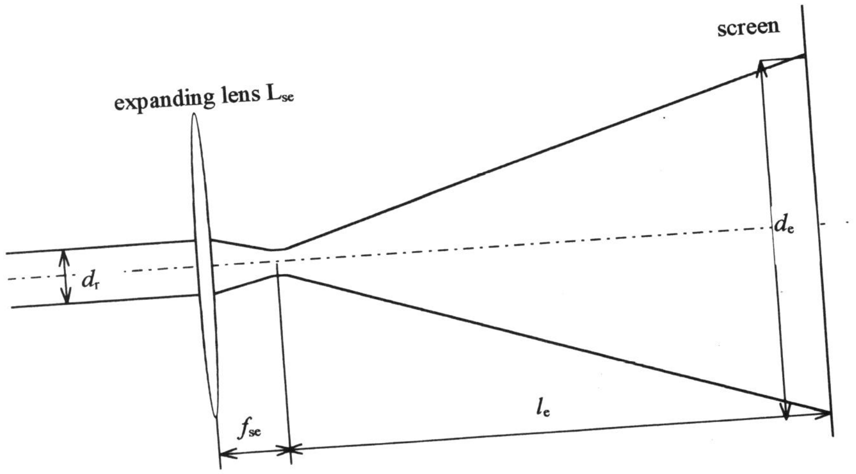

Fig.2 - Schematic representation of the beam image expander