Development of a laser beam to the line in measuring systems

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Abstract. The way of laser radiation focusing on a reception matrix when carrying out measuring works applying a narrowly targeted beam is shown in this article. For example, centering the shaft (reduction to coaxiality) pump units allows preventing emergence of vibration. It is destructive for bearings. The optical scheme consists of several parallels and a photosensitive matrix of glass cylinders. We theoretically prove the possibility of using a system optically of transparent cylinders with the calculated indexes of refraction, including diameters for development of a dot laser beam to the line. At the same time the ratio “the power of a beam/power of hindrances” of a laser beam when receiving the line in close proximity to a reception matrix increases from 10-100 times. This depends on the distance between a matrix and a source of laser radiation. It allows using lasers of the 1 class with power no more than 1 mW. For the purpose of confirmation of feasibility of the developed design, experimental measurements are carried out.

1. Introduction
It is known that excessive vibration of rotor equipment leads to failure of the support system (bearing units), as well as to a decrease in the hydraulic efficiency of pumping units, and in general, to a decrease in the energy efficiency of injection processes. One of the main defects that lead to increased vibration of the units is misalignment of the shafts.

Currently on the market, for conducting the centering of the work units of the “motor-machine” variety of mates (rotary, belt), there are plenty of constructive solutions. They can be divided into two large classes – using radial and axial measurements and using only radial measurements (the so-called inverse indicator method). Laser alignment systems, such as “Fixtur Lazer”, are developing intensively. When achieving comparable indicators for alignment accuracy (~ 1 µm), the main problem is the achievement of the standard powers of the used lasers (less than 1 MW). In particular, for systems with the deployment of the beam in the horizontal plane, this requirement is critical for achieving a satisfactory range (length of the shaft) of about 1 m.

We have obtained a solution that allows achieving a high signal-to-noise ratio on the receiving matrix while maintaining the required laser radiation power.

2. Materials and methods
The length of the matrix is obviously higher than the change of the laser line position even under the biggest possible misalignments. The disadvantage of this method is that the light flux is “spreading” across the full length of the line. It leads to a deterioration of the ratio of the “beam force/disturbance force” ratio (from other light sources), and consequently, to the necessity of increasing the initial power of the laser (figure 1).
The last condition is undesirable as consequently current consumption of batteries increases which accordingly reduces the operational life of the device in an autonomous mode. Presence of the laser beam sweeping system complicates the laser construction that leads to a risk of eye injury as a result of laser radiation.

However, for measurements on large bases (L1~1 m. or more), the geometrical dimensions of the matrix must be large enough for the spot of laser beam must stay inside the matrix. It is especially acute if the misalignment is large (for example, immediately after installation of the unit).

The highly focused beam produced in the laser source falls on the optical system sweeping it in a line, perpendicular to the axis of the light sensitive one-dimensional matrix (figure 2).

Due to the location of the optical system in the immediate proximity to the light sensitive matrix, the light flux on the matrix spreads on a considerably less area. Illumination (power per unit area) of the matrix is enough to compete with light sources.

Moreover the beams of light from external sources of light falling at angles $\alpha$ (figure 3) bigger than 70° become strongly weak.
Figure 3. Beam path falling on cylindrical lens: 1 – optically transparent with refraction index $n$, 2 – beam of light falling at an angle $\alpha$ on the cylinder surface, $\sin(\alpha)=h/R$; 3 – beam refracted in glass (cylinder) at an angle $\beta$ to the cylinder surface; $\sin(\beta)=\sin(\alpha)/n$; 4 – beam, that passed through lens; 5 – light sensitive receiving matrix; $R$ – cylinder radius of optical scheme, $r$ – distance from optical scheme to light sensitive matrix; $\alpha, \beta$ – angles of incidence and angle of refraction (the principle of reversibility is applied).

It results in that the reflexion index $k$ increases sharply (figure 4) compared with the reflexion index $k$ for angles $0^\circ$ to $50^\circ$:

$$k = \frac{(n-n_0)}{(n+n_0)},$$

where $n, n_0$ – refraction indices of glass (cylinder), $\sim 1.5$ and air ($n_0=1.000292$ under ordinary conditions).

Figure 4. Dependency of reflexion index $k$ on angle of incidence $\alpha$.

3. The research of a possibility of a laser beam development to the line

It is possible to apply laser gages consisting of a source of the monochrome highly focused particle beam and a receiving matrix with an accuracy of 1 $\mu$m instead of widely spread dial gauges (accuracy of 10 $\mu$m). This allows one not only to improve the accuracy of misalignment measurement, but also to make the measurement automatically. However, for measurements on large bases (L1~1 m. or more), the geometrical dimensions of the matrix must be large enough. The spot of the laser beam must stay inside the matrix, which is especially acute if the misalignment is large (for example, immediately after installation of the unit).

As a solution to this problem, the developers proposed using a linear array instead of a circular receiving matrix. While the length of the matrix exceeds the changes in the position of the laser line, even with the largest possible misalignments. Then for measurements of position (only in one plane) a ray developed in line [10] is applied (figure 1).

Moreover, to increase the signal-to-noise ratio, the beam is swept into the line not at the output of the laser, but in the immediate vicinity of the matrix by means of an optical system.

This optical system is included in the assembly of the receiving device (one-dimensional matrix). The system consists of a number of optically transparent cylinders adjacent to each other (beam path in figure 5).

The aim is to increase the reliability of detection of the laser spot position by the one-dimensional
matrix. It should not prevent increasing the power of laser radiation and expanding the area of beam sweeping in a line direction.

Besides, to increase the illumination (power per unit area) of the matrix with the use of radiation distance between the optical system r and light, the sensitive matrix satisfies the following condition (figure 3):

\[ r \leq 10^5 \times R \],

where \( R \) – radius of the optical system cylinder.

4. Conclusion

Comparative tests of devices for shaft alignment of “PC-Laser-B” [10] with the optical scheme described above and Fixturlaser-Lazer [8] showed:

- expressiveness of installation of sensors “PC-Laser-B” on a magnetic basis (1 min) in comparison with Fixturlaser sensors on a chain basis (8 min);
- the Express (1 min) and usability settings “PTS-Laser-In” (a comprehensive line of linear matrix length of 30 mm) compared to Fixturlaser – 6 min (point on a circular matrix with a diameter of 10 mm);
- a convergence of results for angular misalignment within 0.01 mm/100 mm, for radial misalignment within 0.01 mm.

Thus, laboratory studies and field tests have shown that the use of the described optical system repeatedly increases the ratio of “laser light/light from third-party light sources” for systems with the deployment of the beam in line.

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