Promising version of the three-objective multipass matrix system

Semen M. Chernin

General Physics Institute, Russian Academy Sciences, Vavilov str., 38, Moscow 119991, GSP-1, Russia
chernin@nsc.gpi.ru

Abstract: Since they were described in Refs. [1, 2], multipass matrix systems have found extensive application in various areas of science and engineering. They provide the longest optical path lengths within a small volume with linear control of the number of beam passages. In the present paper a modified three-objective multipass matrix system is considered. The system is used equally successfully both in high-resolution spectroscopy and in metrology as well-controlled delay lines of pulse optical signals. New potential applications offered by the system that favorably distinguish it from its known analogs are also discussed.

OCIS codes: (120.3930) Metrological instrumentation, (120.4570) Optical design of instruments, (120.4828) Optical systems

References and links

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Contemporary advances in high-resolution spectroscopy are based to a great extent on the use of multipass cells with long optical pathways to enhance instrument sensitivity. Some multipass matrix systems [1] (MMSs) were designed to solve problems relevant to diode laser spectroscopy. MMSs proved to be among the best systems, in terms of their optical and operation characteristics, to be applied in absorption laser spectroscopy. Matrix systems derive their name from a compact rectangular matrix of images produced on field mirrors. They enable extremely long optical pathways to be achieved in devices with large relative apertures. These devices are distinguished by simple design, image stability, very low aberration distortions [2], linear control of the number of beam passages, reproducibility, and reliability of operation.

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As was done for the previously described multipass systems [1-10], the present author developed the new devices as a result of close cooperation with researchers working in various areas of modern science. This cooperation gave rise to multipass devices applied in various areas. Newly arising problems necessitated modification of MMS devices. Further development of MMSs was reported in the author's recent publication [11]. However, some matrix systems already have uses beyond molecular and analytical spectroscopy. They help to solve various problems that arise in metrology, for instance, as controlled delay lines for optical signals in the nanosecond range. In contrast to the four-objective matrix system the three-objective matrix system is particularly convenient for delay lines owing to its single-image array formed at the focal matrix points. Light pulses in this system are recorded by photodetectors with appropriate time delays. The photodetectors were mounted upon the rear sides of translucent field mirrors. The aforesaid matrix system was used as an optical delay line in instruments that record fast processes, namely, in calibrating the sweep velocity in optoelectronic cameras, in instruments designed to study the kinetics of fast elementary processes involving short-lived radicals, and also in kinetic investigations of the fluorescence processes that take place in complex organic molecules, including dyes. Having great number of focal matrix points enables one to take snapshots of fast processes.

Increased interest in matrix systems stimulated the author to write a short communication about modification of the three-objective system [1] and also to provide additional information about this system, which had not been done in the previous publication on development of MMSs [11]. Although the three-objective MMS has fewer beam passages than the four-objective system, nonetheless a onefold alignment of images at fixed matrix points renders this system much more versatile and capable of solving many problems associated with optical measurements. The device for vertical image displacement in this system comprises only reflecting elements and has a number of advantages compared with the Schulz-DuBois device [12] that was designed for the same purpose. To displace an intermediate image vertically the Schulz-DuBois instrument incorporated an angular reflector of complicated geometry with a focusing lens. Therefore images are constructed in this system at a strictly defined wavelength. Furthermore, in the system taken for comparison [12], following White's concepts [13], the mirror objectives were manufactured such that they are decoupled from each other, which cannot guarantee proper stability of images. Reference [11] clearly illustrates the principle of image stability in a system with mechanically coupled paired objectives, that is inherent in all matrix systems without exception. The Schulz-DuBois mirror-prism system [12] is a closed optical cavity that has no exit opening and is used only to delay optical signals recorded on the rear side of the low-transparency field mirror. That the exit point is missing in a multipass system limits the system's ability to record single light pulses.

Unlike the optical system described in Ref. [12] a three-objective multipass matrix system (Fig. 1) constructs images within a very wide spectral range. After formation of two image rows produced by paired mirror-objectives 3 and 4, the auxiliary field mirror 9 directs the light beam to an additional mirror objective 10, which sends the beam back to the field mirror 9 and shifts it vertically. Then the light beam is again directed to mirror objective 3, which is the first on the beam path, as if from a new entrance opening. The next pair of image rows is formed, and so on, until the last image enters the exit opening 2. In this system the optically coupled pair that comprises the auxiliary field mirror 9 and the additional mirror objective 10 returns the beam to the field mirror 9 with a vertical shift each time the cycle of constructing two image rows is finished, as if new entrance points are being produced at different heights.

Running the system for several years has shown that an essential drawback of MMSs of the first generation [1] arises because the entrance and exit openings are positioned close together (positions 1 and 2 in Fig.1 for a three-objective system), which makes separation of the light beams and alignment of the radiation source and detector in the device difficult. The close proximity of the entrance and exit openings is particularly inconvenient when the device is matched to instruments with a large angular beam divergence, such as diode lasers. It may seem strange but, as far as I know, in the decade following the first publication on matrix systems [1] no experimentalists have

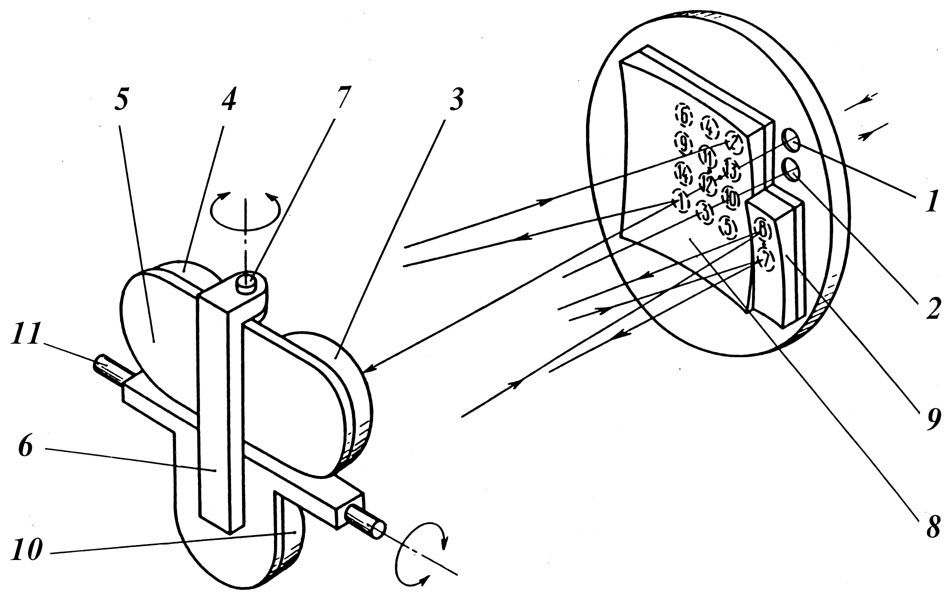

Fig. 1. Three-objective MMS: 1, entrance opening; 2, exit opening; 3, 4, paired mirror objectives; 5, turning plate; 6, movable holder; 7, vertical axis; 8, field mirror; 9, auxiliary field mirror; 10, additional mirror objective; 11, horizontal axis.

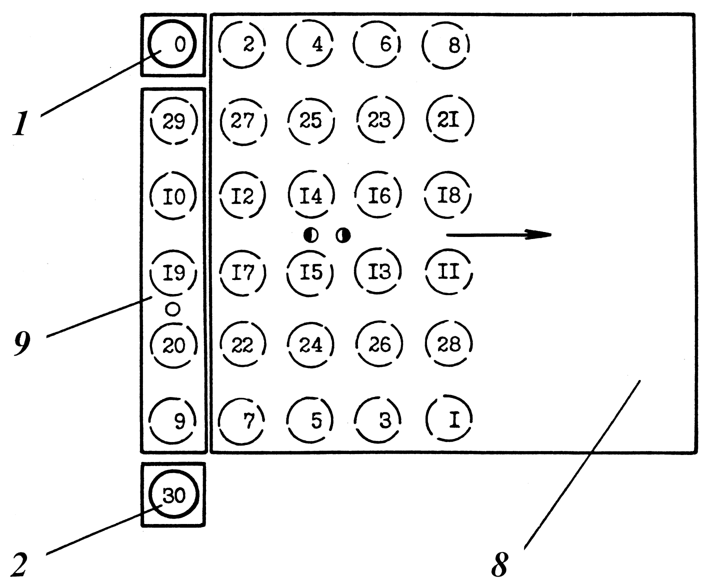

Fig. 2. Modification of the three-objective MMS. View of field mirrors: 1, entrance opening; 2, exit opening; 8, field mirror; 9, auxiliary field mirror.

attempted to increase the distance between those openings. However, to implement this modification, one has to understand clearly the geometric scheme of the rays in space. Changes were made only in the field mirror block, at the expense of correction of the design and beam pattern. Figure 2 shows the newly modified three-objective MMS viewed from the side of objectives toward the field mirrors with 60 beam passages. Components of the system are located in the same places as in Fig. 1. For better illustration the entrance 1 and exit 2 openings are positioned to the left of the main field mirror 8. The widely separated entrance 1 and exit 2 openings are positioned above and below the auxiliary field mirror 9 which makes separation of the light beams and mounting of the source and detector much easier. The centers of curvature of the mirror objectives 3 and 4 are situated in the horizontal axis of the field mirror 8. These centers are indicated in Fig. 2 by half-filled circles; the distance between these circles is constant. An open circle below the auxiliary field mirror 9 in Fig. 2 shows the position of the center of curvature of the additional mirror objective 10 in Fig. 1. The numbers in the dashed circles indicate the order of formation of intermediate images on the two field mirrors 8 and 9. As the centers of curvature move in the direction indicated by the arrow, the field mirror 8 keeps being filled with images, and the number of passages increases.

It should be emphasized that the modified system features only onefold alignment of images. When the system is used as an optical delay line and its mounting in a tubular cell is unnecessary, it is advisable to mount the mirror objectives along a single straight line. Basic approaches to mutual arrangement of the objectives of matrix systems were discussed in Ref. [1].

The number of passages N in the modified three-objective matrix system is determined by the formula:

$$N = 2mn, \tag{1}$$

where m is the number of rows that make up a series of even numbers 4, 6, 8, 10... and n is the number of columns that form a series of natural numbers 3, 4, 5, 6...

The present publication is a continuation of the cycle of publications on the development of new multipass systems [1-11] intended to solve many contemporary scientific problems.