The cryostat has proved sufficiently successful to warrant the building of a second model. The only major modification contemplated in the second model is the replacing of the common brass plate, between the upper and lower halves of the outside vacuum jacket, with two brass plates bolted together and vacuum sealed with an O-ring.

Though the immediate object was to construct a cryostat for use between the poles of a relatively small electromagnet, the principle of an elliptical cross-section tail piece could be applied more widely. In particular, the general design would seem to be ideally suited for modification for optical work since it would not be necessary to have any windows in contact with cryogenic liquids.

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Use of an XY oscilloscope in interferometric measurements of small displacements

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Abstract A laser interferometer for the accurate measurement of displacements is described. The use of an XY oscilloscope leads to a simple design and an easy adjustment of the interferometer and improves the resolution of the system to about 4 nm.

1 Introduction
For the measurement of small displacements, or large displacements with high accuracy, many designs based on a laser interferometer have already been published. In this note we describe a laser interferometer used to measure the linear displacement of a positioning table in the range of several centimetres. The position of the table is displayed on a reversible counter with an accuracy of ± 0.079 μm (± 1 count). The counter must be fed with two signals, harmonically dependent on table position and with a phase difference of 90°, in order to determine the count direction. The signals are generated by two photodiodes placed in the same fringe pattern. However, it is then necessary to design and eventually to adjust the interferometer very carefully to obtain the proper phase difference.

The use of an XY oscilloscope as a monitor of the diode signals makes the adjustment of the interferometer easier; the design of the interferometer can therefore be simple and the demands on the quality of the optical components relatively low. The horizontal and vertical amplifiers of the oscilloscope are also used to adapt the signal amplitudes and levels to the trigger levels of the reversible counter. This adaptation can be monitored on the oscilloscope screen as well. The XY oscilloscope offers the possibility of improving the resolution for static measurements to a minimum of about 4 nm.

2 The interferometer
The interferometer is of the Michelson type in which mirror C is attached to the moving object while the other mirror D is fixed (see figure 1). The outgoing beam E of the interferometer contains, after coarse alignment, an interference pattern consisting of dark and bright fringes. When the object mirror moves perpendicular to its own plane (the displacement being characterized by the coordinate x), the fringes move sideways in a direction perpendicular to themselves.

If a photodiode, whose sensitive area is small enough, is placed in the fringe pattern it generates a photocurrent $i(x)$, which is given approximately by

$$i(x) = i_1 + i_2 \sin \left( \frac{4 \pi x}{\lambda} + \phi \right).$$

$i_1$, $i_2$ and $\phi$ depend in general on the position of the photodiode in the fringe pattern and the alignment of mirrors and beamsplitter in the interferometer. Therefore it must be possible to introduce a second photodiode in the fringe pattern, which produces a photocurrent

$$i_3(x) = i_3 + i_4 \sin \left( \frac{4 \pi x}{\lambda} + \phi + 90° + n180° \right)$$

($n$ is an arbitrary integer). The phase difference of ± 90° with respect to $i(x)$ is necessary for proper operation of the reversible counter L and for the utilization of the XY oscilloscope I as a measuring instrument.

However, the area of the cross section of the fringe pattern is too small to accept two photodiodes. This problem is solved by using a beamsplitter and positioning a photodiode in each resulting beam. In our set-up we used a small silvered prism as a beamsplitter, as shown in figure 1.

The above procedure is possible even with a rather irregular fringe pattern, which lowers the demands on the quality of the optical components. Of course the shape of the fringe pattern must not change with time or as the object mirror moves, but this can be achieved by sufficient ruggedness of construction.

3 The XY oscilloscope
In general it will not be possible to adjust the interferometer and the photodiodes for 90° phase difference of the photocurrents without checking the signals themselves. Moreover, it will probably be impossible to achieve 90° phase difference together with nearly equal signal amplitudes.

In order to check the phase difference between the signals they are displayed on an XY oscilloscope I. As long as the object mirror is at rest with respect to the interferometer construction, the diodes produce direct currents. The spot on the oscilloscope screen does not move and there is no way of determining the phase difference. However, the aim of the set-up is to measure the position of a moving object.

When the object moves (which may be a translation as well as a vibration), the spot moves on the oscilloscope screen. The pattern described by the spot will reveal the phase difference and the amplitudes of the signals of the photodiodes. It is thus possible, with a moving object mirror, to...
Figure 1 The laser interferometer system for the measurement of small displacements: A, He–Ne laser (Spectra Physics model 120); B, beamsplitter; C, object mirror; D, fixed mirror; F, silvered prism; G, photodiodes (HP-5082-4220); H, preamplifiers, mounted on interferometer construction; I, oscilloscope (Tektronix 561A); K, plug-in units (Tektronix 3A9); L, reversible counter (Elesta PCU 600A11)

fine-adjust the interferometer. This can be done in several ways: for instance by tilting the object mirror or reference mirror (which changes the fringe separation), or by shifting the photodiodes or the silvered prism. The interferometer is adjusted until the oscilloscope displays an ellipse with horizontal and vertical axes.

The plug-in units K of the oscilloscope are supplied with signal outputs, which provide DC coupled signals at approximately 1 V per displayed division of the graticule. These signals are zero when the spot is in the centre of the screen. We have fed these signals to a reversible counter 1, the trigger levels of which are ±1.5 V. It is convenient to represent these trigger levels on the graticule of the oscilloscope screen by horizontal and vertical lines. This makes it easy to adjust the output signals of the plug-ins for proper triggering of the counter with the aid of the sensitivity and position controls of the plug-in units.

The count direction depends on the phase difference between the input signals and therefore on the sign of the velocity of the object mirror. The device counts every zero crossing of both input signals leading to a resolving power of \( \frac{\lambda}{8} \) per count (\( \lambda = 0.079 \) μm for the applied He–Ne laser). The error, which is a result of the fact that the trigger levels are different from zero, can be estimated by comparing the signal amplitudes and the trigger levels on the oscilloscope screen. If the signal amplitudes are much larger than the trigger levels of the counter the adjustment of 90° phase difference is not very critical.

4 The XY oscilloscope as a measuring device

Generally the movement of the spot will be elliptical, if there is adjustment for 90° phase difference between the photocurrents. However, with the sensitivity controls of the oscilloscope plug-in units this ellipse can always be changed into a circle. Then the angular movement of the spot is proportional to the displacement of the object mirror. The position of this mirror is given by

\[
x = \frac{\lambda}{2} \cdot \frac{\alpha}{360} \text{ (x in degrees, } x \text{ and } \lambda \text{ in the same units). With the aid of a polar graticule on the oscilloscope screen the angular position of the spot can be observed with a minimum resolution of about 5° (depending on parasitic movements and noise), which leads to a resolution of the displacement measurement of about 4 nm. This procedure can only be followed with static measurements.

5 Conclusions

In a laser interferometer used with a reversible counter an XY oscilloscope can perform the following functions: (i) monitor the adjustment of the interferometer; (ii) match the diode signals to the reversible counter; (iii) measure static position with a resolution of 4 nm. The profits gained from (i) and (ii) can be used to simplify the interferometer. The complete instrument is inexpensive and easy to produce in standard laboratory circumstances.

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