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Institute of Applied Physics
(Nizhny Novgorod, Russia)
Six Month Progress Report
February 15, 1999

This report describes work of the Institute of Applied Physics group in support of the LIGO program over the past six months.

1. Advanced White-Light Interferometers for Preliminary Control of Optical Components

Recently Dr. I.Kozhevatov, N.Cheragin and E.Kulikova carried out experiments to provide measurements of LIGO component quality with the aid of an original home-made white-light interferometer, where the preliminary calibration of reference surfaces was used. The main feature of our interferometer is a temporal scanning of spectral components of the probing white light combined with the lock-in detection. The white-light interferometry offers the following advantages over traditional phase modulation interferometry schemes:

1. A possibility of tuning the illuminated light spectrum according to the distance between the measured and reference surfaces to suppress interference with other reflections. This may be important in the case of non-uniform cross-section reflectance distributions.
2. A possibility to avoid the influence of secondary reflections on interference patterns.
3. The interference pattern does not possess any speckle-nonuniformity which plagues coherent laser illumination.

There is no modulation of distance between the interferometric surfaces. Thus, the sample and reference plates are quiet during measurements, which is especially important for wide-aperture optics.

The scheme of our interferometer is shown in Fig.1. A damping mount (3) supports the case for a sample (1) and a transparent reference plate (4). They are placed on a stabilized optical table (2) to decrease the influence of external mechanical vibrations. The illumination is provided by a white light source (11) which is collimated by a lens (5), spectrally modulated using a dithered Fabry-Perot cavity (10) and delivered to the interferometer via a fiber bundle (9), a spreading lens (8) and a collimating lens (5). A frequency stabilized He-Ne laser is used to actively stabilize the Fabry-Perot modulator. The modulation of the white light results in a train of spectral peaks shifted linearly in time. The dither voltage from a synchronization unit (17) is controlled by a servo-loop (not shown) to adjusts spectral peaks of the Fabry-Perot transmission function and the interferometer response function. The reflected beams after a beamsplitter (6) pass a spatial filter (7) to a CCD-camera (15). A PC (16) is used to control the dither signal, data acquisition and processing of the phase pattern.

The setup has demonstrated the following characteristics:

a) root-mean-square accuracy $\lambda/1000$;

b) scale of the irregularities (in the processing area) from several microns to 80 mm;

c) processing area 60 x 80 mm;

d) measuring and processing time for a 240 x 320 pixel phase pattern less than 10 min.

Based on the created device and accumulated experience of its operation, now they are developing several new facilities to provide reliable preliminary testing of LIGO optical component, that will satisfy all requirements of the LIGO project.

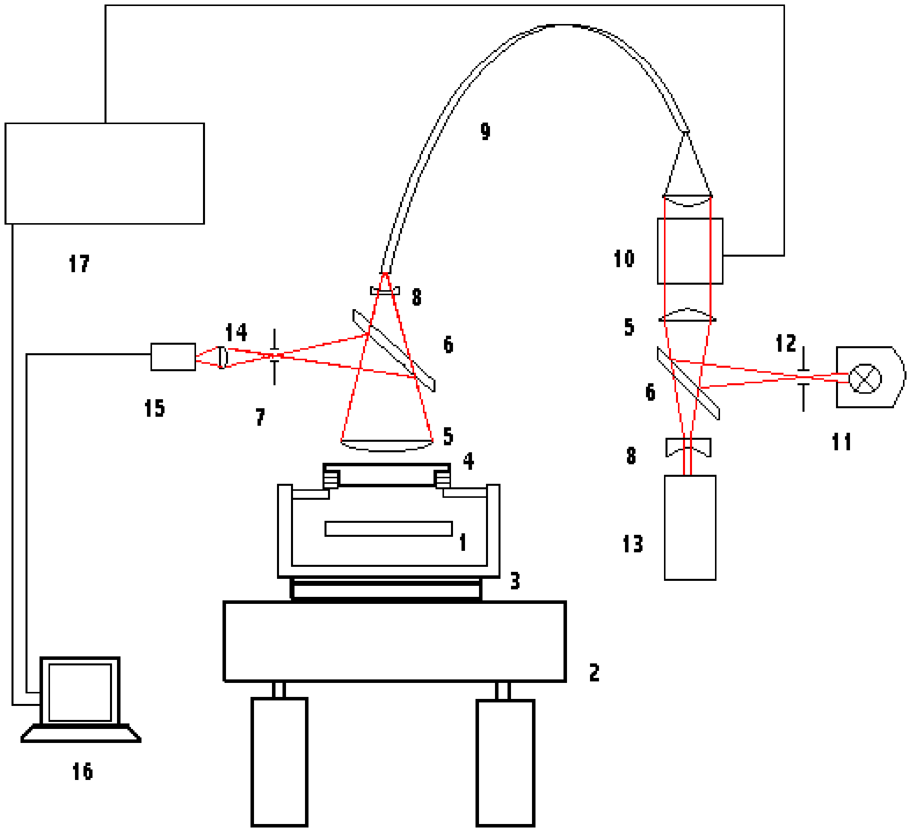

Fig.1. Scheme of interferometer.

Here: 1 - sample; 2 - stabilized optical table; 3 - damping mount; 4 - reference plate; 5 - collimating lens; 6 - beam-splitters; 7 - spatial filter; 8 -lenses; 9 - fiber bundle; 10 - illuminating light spectral modulator; 11 - white light source; 12 - aperture; 13 - frequency stabilized He-Ne laser; 14 -projection lens; 15 - CCD-camera; 16 - computer; 17 - synchronization and control block

2. Study of LIGO optical component performance under high-power CW radiation loading. Self-induced thermal effects in Faraday isolators

Our preliminary study on this problem have been connected with thermal effects in Faraday isolators. The importance of this study namely for this LIGO components is due to the following factors:

- relatively high volume absorption in magentooptic material (10^{-3} cm^{-1}) as compared to another transparent optic elements (10^{-6} cm^{-1});
- small self-induced birefringence superimposed on relatively high circular birefringence (Faraday effect) makes the depolarization effect different as compared to the case of initially isotropic optic element;
- depolarization in Faraday isolator leads not only to beam quality deterioration but to a decrease of the isolation ratio;

Faraday isolator induces not only phase distortions in the passed beam (as other transparent optic elements) but also amplitude distortions.

Dr. N. Andreev, E.Khazanov, O.Kulagin and O.Palashov studied two polarization effects in Faraday rotator. First of all, the angle of rotation changes due to temperature dependence of the Verdet constant. The second effect is birefringence due to the photoelastic effect of thermal strains. In this case initially isotropic media obtains linear birefringence and initially circular eigen polarizations (Faraday effect) become elliptical ones both in case of Terbium Gallium Garnet (TGG) and magneto optical glasses. Angle of incline of their axes, their ellipticity and phase delay between them vary over the cross-section. So at each point of the cross-section the beam polarization changes according to these values. As a result the polarized (the same polarization over all cross-section) input beam becomes depolarized one at the output. In these works in order to find isolation ratio we at first derived the Jones matrix for each point of the cross-section. After that we found the output beam and depolarized part of it. Integration of depolarized energy over all cross-section gave us the depolarization ratio as a function of beam power, beam radius, angle between incident polarization and crystal axis, characteristics of the magnetooptical material. Influences of two mentioned above effects were analyzed and compared.

Now the investigations in the following directions are under development.

1. The *photoelastic coefficients and thermooptic characteristics* of TGG and other magneto optical materials.
2. Preliminary estimations show that traditional scheme of Faraday isolator (polarizer – 45^0 Faraday rotator – half wave plate – polarizer) do not satisfied the requirements of next generation of LIGO. Dr.N.Andreev and E.Khazanov investigate *new schemes which allow to reduce influence of self-induced thermal effects*. One of the way to do it is usage of the scheme like polarizer – 22.5^0 Faraday rotator – reciprocal element – 22.5^0 Faraday rotator – half wave

plate – polarizer. The idea is as follows. The distortions induced in the beam in the first rotator will (partially or completely) compensated in the second one. The reciprocal element may be half or quarter wave plate, reciprocal polarization rotation, lens, high absorption element or their combinations. This experiment (measurement of depolarization in various schemes in depend on laser power) is carried out using the CW radiation of diode-pumped Nd:YAG laser (532 nm; output power is up to 5 W). We will determine the element which provide the most reduction of polarization and other distortions. Also we plan to search another way to compensate the self-induced thermal distortions.

3. Novel techniques for *in situ* quality control of LIGO optical components

Probably, the most challenging problem in testing quality of LIGO optical components is to elaborate techniques for high-precision, non-disturbing probing of surface and bulk materials during the LIGO operation. The most sensitive detector components including those of the main interferometer will be located in the vacuum chamber, which makes impossible to use not only contact methods of probing but also interferometric techniques. Dr. O.Kulagin, A.Potemkin and A.Mal'shakov continued to investigate a new approach to the problem of remote sensing, that is based on ideas and technologies developed in nonlinear optics.

3.1. Remote testing of wave front distortions using phenomenon of self-focusing

To increase the sensitivity of wave-front phase measurements Dr.A..Potemkin and A.Mal'shakov have proposed and demonstrated experimentally a novel testing technique based on measurement of map of optical angle difference (OAD). The main feature that distinguishes our technique from any other is that a laser beam, having passed through a sample, propagates further in a special nonlinear medium under the condition of self-focusing. Here, a self-focusing "point" (SFP) occurs in the far beam zone. The actual size of this "point" a_{sf} depends on laser light parameters and a type of nonlinear medium, but it is important that it can be much less than the linear diffraction waist a_d . The large parameter of a_d / a_{sf} provides a proportional increase in accuracy of the nonlinear OAD technique as compared to conventional linear methods.

To demonstrate this idea experimentally, at the initial stage they employed pure water and some organic liquids as a nonlinear media. The laser wavelength was 0.53 μm (second harmonic of Nd:glass laser radiation with the pulse duration of approximately 1 ns). The accuracy of wave front inclination measurements achieved in this experiment was no worse than λ/650. The major reason why the accuracy was limited to this value is the minimal size of a_{sf}. Mechanisms restricting a_{sf} can be different for different media and different pulse durations. To our knowledge, no research has been performed to find optimal media and laser light parameters so as to achieve minimally possible SFP size. There are, however,some experimental data regarding self-focusing of picosecond light pulses in Kerr liquids. According to these data, the SFP as small as 10 μm was produced. The Kerr liquids used in testing setups for precision optics have the major disadvantage of the thermal liquid motion in a cell which introduces errors in the final result of measurements. From this standpoint, the use of solids, e.g., glass, as nonlinear media is more preferable.

3.2. Remote monitoring of optical surface quality using phenomenon of phase conjugation

Dr.O.Kulagin has developed a prototype laser projection image receiver (LPR) for remote measurements of small scattering based on four-wave interaction of light with hypersound in a nonlinear medium. The functional scheme of LPR includes a hypersound four-wave phase-conjugate mirror, a laser pumping system and a preliminary laser amplifier with broad viewing angle. A studied object surface with small-scale scattering impurities is illuminated with a Q-switched Nd:glass laser. LPR amplifies this signal and due to phase conjugation produces an image of the object surface without distortions.

The combination of a PCM and a laser amplifier makes the parameters of the receiver unique. In particular, the sensitivity is 4.8×10^{-19} J (~ 2 scattered photons per pixel), the viewing field is broad (350×350 pixels), the coefficient of weak signal amplification of the receiver is 10^{12}. Such set of parameters allows one to carry out the remote sensing of optical surface characteristics even in the presence of an intense background. In test experiments, he has performed remote measurements of surface parameters of various high-quality optical elements (roughness up to 0.5nm) including a mirror presented by the LIGO project for testing MIT prototype interferometer. The distance between the sample and the detector was in correspondence with the path from a LIGO test mass to a viewing port (~ 2 m). So, as a conclusion we can state that our non-linear image amplifier system using enough small signal energy densities of the order of 10^{-3} J/cm^2 is suitable for remote sensing with the quantum sensitivity of supersmooth surfaces with roughness near 0.1nm and object resolution 0.01mm.

Another possible physical effect in the base of a nonlinear optical image receiver with quantum sensitivity could be the Stimulated Raman scattering (instead of four-wave-mixing). Dr.O.Kulagin is carrying out experimental investigation of this image receiver.

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