9th INTERNATIONAL SYMPOSIUM ON MEASUREMENT AND QUALITY CONTROL (9th ISMQC)
November 21 – 24, 2007, IIT Madras

OPTICAL MEASURING TECHNOLOGY FOR OIL DRILLING PLATFORM

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Abstract: *An opto-electronic measurement system for continuous monitoring of displacements and analysis of the friction pendulum bearings for the oil-drilling platforms is presented. Measuring principle of the system is based on target image formation by camera and digital image processing. The passive part of the system (optical target) is fixed on one part of construction while active part - a field measurement sensor (FMS) - is installed on another part of construction that moves relative to the first one. The system is certified as a measuring tool for the use in explosive environments.*

Key words: *pendulum bearings, noncontact measurement, image processing, continuous operation.*

1. INTRODUCTION

The safety of industrial constructions often takes continuous monitoring of displacements of different parts relative to each other. As it is known, the mining of oil and gas offshore is carried out using the drilling platforms, which are extremely massive (the platform weight is 28 000 tons, the platform dimensions are about 80×100 m^2) and inert. The platforms comprise huge multi-story constructions, which are mounted on the top- side of a few (usually four) supporting legs. The legs are directly installed on the sea floor.

Between each leg and the platform there are intermediate mechanisms such as sliding bearings (friction pendulum bearings). The purpose of the bearing is to suppress the mechanical stress in the platform structure when the legs (located underneath the platform) are moving around their stable position. Such legs movements are caused by certain external factors: waves during the storms, strong underground currents, movements of the surface ice sheets (during the winter time), earthquakes, etc.

The bearing consists of three main parts. One part is rigidly connected with the leg (lower part). Another part is attached to the platform (upper part). The third part is the intermediate piece (located between lower and upper parts), which has ability to slide and turn round between the rigid lower and upper parts in such a way that during the absence of any external disturbance all three parts come into initial resting position under gravitational forces (position with lowest potential energy).

All three parts are constantly moving due to the external disturbances. That causes their constant sliding against each other. The friction causes wear of the parts. If the cumulative traveled (movement) distance exceeds 3 km, then the parts can fail. The cumulative traveled distance is the most important parameter, which characterizes the safe platform operation and it is very important to monitor that parameter with the relative error less than 0.01%.

Another important safety-related parameter is the maximum displacement value of the bearing parts from the initial resting position. This maximum displacement should not exceed 350 mm in any possible direction. This parameter has to be measured with error less than 1 mm. It is necessary to take into account, that the relative movements of 200-300 mm with the relative velocity of up to 1.5 meters per second are possible. In such conditions the measurements of the relative platform position have to be carried out with the frequency of at least 10 measurements per second.

As a rule, the noncontact methods have to be utilized for that purpose; a relatively high measurement frequency no less than 10 meas./sec is required. Measurements have to be carried out for a wide range of displacements (X × Y × Z space) with high relative accuracy. For this purpose the automatic optical-electronic system for measurements of bearings movements has been developed. Its main aim is continuous noncontact measurement of the bearing location and calculation of the total distance traveled by the bearing for any defined time period. The description of the opto-electronic measurement system for continuous monitoring of displacements and analysis of the friction pendulum bearings for the oil-drilling platforms are presented below.

2. SYSTEM ARRANGEMENT

The operation of the measurement system is based on target image formation by camera and image processing of the acquired images inside the system. The schematic view of the proposed system is shown in Fig. 1. The system consists of two parts. Passive part of the system (the target, see in Fig. 2) comprises the metal sheet with the special optical marking on it. The target is fixed to the platform leg and its plane surface is perpendicular to the vertical axis. Active part of the system – the Field Measurement Sensor (FMS) is located on the lower deck of the platform. FMS comprises the high-performance video-camera illumination unit and electronic hardware for the acquired image processing and computation.

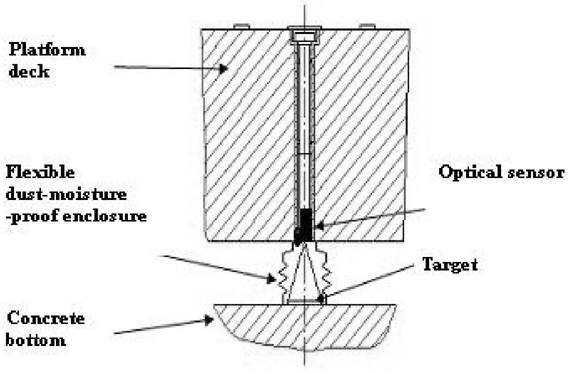

Fig. 1. Scheme of the sensor arrangement

During the system operation the image of the target is captured continuously. The acquired images as captured video frames are continuously processed. When platform and the legs are displacing relative to each other, such displacements can be recognized from the images. The image processing can measure the relative displacements with high degree of accuracy.

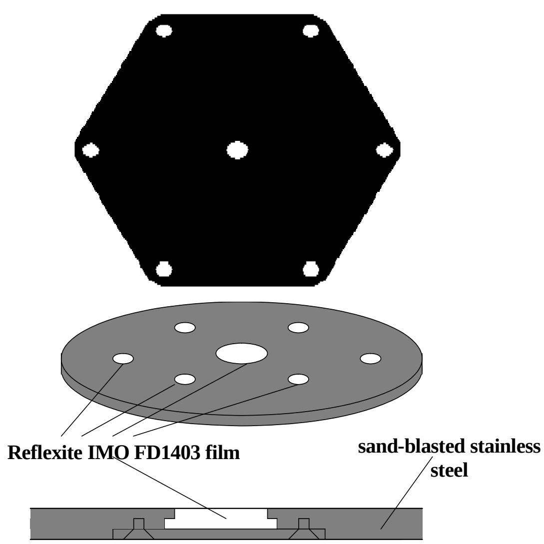

Fig. 2. General view of target

Functionally the friction pendulum bearings are intended for reduction of mechanical deformations of platform, which arise at displacement of support leg on which the platform is based. The given task can be reduced to the measurement of relative displacement of two planes (platform top-side plane and platform leg surface plane) with the distance between them of 0.8 meters. The relative displacements of up to 350 mm in any tangential and 15mm in normal directions are possible.

The optical sensor FMS works autonomously. All measurement sensor data are transferred to the control panel, which is located remotely at the oil-drilling platform. FMS is housed in the explosion protective enclosure (Fig. 3).

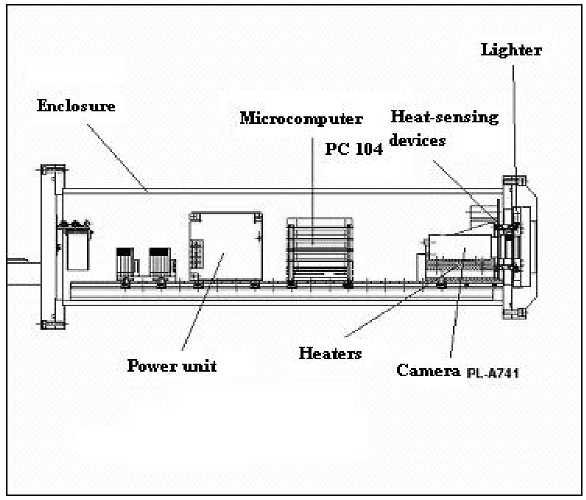

Fig. 3. Interior arrangement of the optical field measurement sensor

3. OPTICAL TARGET IMAGE

In the current optical sensor the high performance machine vision video camera PIXELINK PL-A741 captures the images of the target and transfers them via Firewire (IEEE-1394a) (Standard, 2000) interface. The camera is connected with PC 104+ computer with Firewire interface card, supporting OHCI standard. Camera allows data transferring with the rates of up to 400 Mbit/s; that corresponds to the 30 frames per second for the image size of 1000 × 1000 pixels and 8 bits brightness. For synchronization of the captured frames with external device, the camera has a trigger feature, which can work in a few different modes. Camera has a set of software-controlled parameters: resolution in pixels, 8 or 10 bits brightness, gain, exposition time, and trigger modes. The illumination unit is designed on the LEDs, working in pulse mode. LED's wavelength is matched to the spectral sensitivity of the camera. The illumination unit includes the double ring of the LEDs, which are located very close to the camera optical axis that allows capturing images with very good signal to noise ratio when working with retro-reflective target surfaces. The illumination unit provides high intensity light pulses with the frequency of 30 Hz. The duration of the single light pulse is 0.3 ms.

In order to synchronize the camera exposure and the illumination the camera is triggered directly from the illumination unit. Inside the explosion protective enclosure a few thermal sensors and heater are located. The temperature feedback control makes possible temperature stabilization when the ambient temperature is out of the working range, allowed by other sensor components, like video camera.

The target includes a steel sheet with characteristic dimension of 800 mm, which incorporates seven retro-reflective film-type reflectors. Each of reflectors is positioned with absolute error better than 10 micrometers. The retro-reflective film has micro-prism structure, which allows us to reflect maximum light energy to the reverse direction of the incident light.

In the target center a spot with diameter of 45 mm is located. The side spots are located at equal distances of 260mm from the target centre. The diameter of each side spots is 35mm. The target and illumination unit design allow increasing the SNR and corresponding contrast of the captured image dramatically. That simplifies the image algorithms analysis.

4. IMAGE PROCESSING ALGORITHMS

The input image under processing is monochrome with 1000 × 1000 pixels and 8 bits brightness. Image consists of dark background, which contains bright spots that are images of target reflectors. The majority of the pixels in the spot element of the image have value of 255. It is acceptable that the image can also contain the objects, which do not belong to the useful signal. Some of the spots can be outside of the camera view. Some of them can be displayed partially, if the spot is on the image border or the target becomes damaged. Linear size of the spots can vary in the range of 20 percent from the normal value. That is due to the scaling effects caused by 3D movement of the target.

The measurements were carried out in the coordinate system, which zero point corresponds to the position of the target central spot in the center of the image. The displacements measurement task was solved in two stages:

1. Finding a set of the linked image components with continuous brightness (spot images, artifacts, etc).
2 Filtering the acquired list of components and finding the useful components in it. Checking the geometry of the proper image spots.

The final coordinates of the target position can be obtained by transformation of the brightness mass centers of selected spots into the physical coordinates.

In ideal case (perfect objective) all the coordinate distortions can be adjusted by applying image scaling relative to certain image centre. However, the real optical scheme contains distortions, which also change the image scaling. These aberrations are caused by objective and thick protective glass of the explosion proof enclosure.

Therefore in order to measure the real spots displacements, the device has to be calibrated first. Calibration of the distortions is done polynomially, with the third order form, which coefficients were found by optimization algorithm, based on simulated annealing.

5. THE ALGORITHM FOR THE CONTINUOUS IMAGE COMPONENTS SEARCH

The acquired image is decimated on both coordinates (X and Y) and scanned. The decimation coefficient for X and Y coordinates is equal to p = 20.

Since every 20^{th} pixel in X and Y direction is scanned, only the pixels are selected whose level is more than some threshold value. This parameter has an integer value, which is stored in the configuration file. The decimation step p = 20 has chosen in such a way, that all the image spots, formed by side reflectors, are to be captured inside the decimated image.

If the brightness value of the pixel is above the threshold, then we assume that this pixel belongs to some continuous bright object, whose statistical parameters have to be estimated. For this purpose the recursive flood-fill algorithm is utilized on the real image each time the pixel in the decimated image is above the threshold. The flood-fill recursive algorithm is described in (Gonzales, 2005; Pratt, 1982; Shikin, 2000; Sonka, 1998). Such procedure will reveal the continuous bright spots on the image. The spots are further analyzed and if their preliminary dimensions are inside the acceptable range, then this spot is presumed to be a spot formed by one of target reflectors. As soon as such spot is detected, its pixel's center of mass is calculated on the basis of the pixel brightness information. The algorithm is schematically shown in Fig. 4.

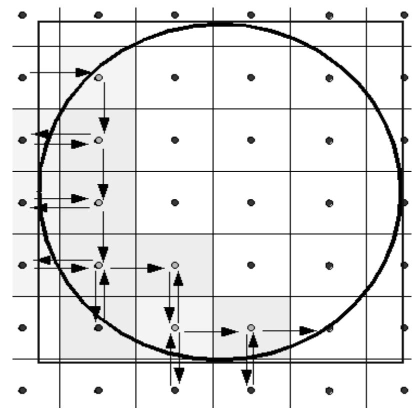

Fig. 4. Scheme of filling algorithm

The proposed algorithm is efficient for the flood-filling of the convex area, which gives at least one pixel in the decimated image. In principle, the algorithm allows detection of arbitrary shape continuous convex bright spots, with assumption that the decimation step is less that the minimum size of the spot required to be detected.

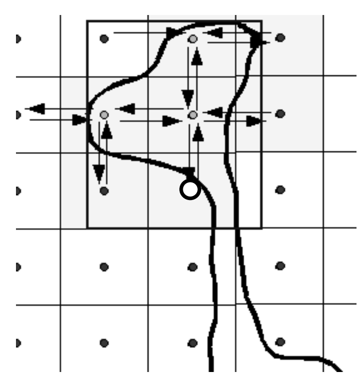

Fig. 5. Incompletely filled coherence area

Figure 5 shows a continuous spot, which cannot be guaranteed to be detected with this algorithm, since the area of the spot has concaved shape. The implemented algorithm allows real-time processing and analysis of at least 30 frames per second, which corresponds to the maximum camera performance.

6. THE FILTERING ALGORITHMS FOR FOUND COMPONENTS

Found bright spots are the images of the target reflectors, which have to be good approximations of circles. Since the target can move in 3D space in the arbitrary way, then the image spots can have circles, which have changing radii. Besides the central spot has larger size then the side spots. It means that the number of pixels per spot cannot be robust criteria of filtration. Among the criteria, which are invariant to the image scale the following ones were selected:

1. The ratio of the sides of the limiting rectangle.
2. The distance from the spot centre to the centre of the limiting rectangle.
3. The average brightness of the found spot.

Applying such criteria the selected components can be an image of the target reflector (side of central reflecting spots on the target), or some type of noisy object. The parameters and thresholds of all the mentioned criteria are specified in algorithm configuration file.

As soon as all the reflective spots images were found, the central spot has to be extracted from that set. It is determined as the component, which has the largest size in pixels. Also the distance from its centre to the centers of the remaining spots belongs to an acceptable range.

7. EXPERIMENTAL RESULTS

The system tests were carried out for compliance to all technical requirements: explosion proof protection, requirements of electromagnetic compatibility, wide working temperature range, marine conditions, absolute measurement accuracy, and accumulation of the measurement error.

Table 1. The system final test results

Parameters	Value
Relative central (to the measurement range) spot coordinate measurement error	≤0,1%
Absolute central spot coordinate measurement error, mm	≤ 0.6
Long-term relative error for the calculated travel path of the target relative to the optical sensor	≤0,01%
System spatial resolution, mm	≤ 0.04
Measurement range on X & Y axes, mm	± 350
Measurement rate, meas./sec	30
Maximum target movement speed, without accuracy loss, m/sec	≥ 4
The working temperature of the control panel (°C)	0 to 40
The working temperature of the optical sensor and target (°C)	-39 to +40
Ambient atmospheric pressure, kPa	84 to 106.7

During the tests the system has shown robust performance of the algorithm for the image spots detection. The measured system resolution is 0,04 pixel, which corresponds to 0.032 mm (for assumption of ideal optics). Using the polynomial image distortions calibration, the resulting absolute accuracy of the system of ±0.6 mm was achieved (in the full measurement range of ± 350 mm). The system final test results are shown in the Table 1.

The industrial system has been tested and certified with more than 20 certifications in different fields (metrology, EMC, climatic tests, Exd, etc). The system is to be installed on the LUN-A platform on the shelf of Sakhalin Island, Russia.

8. CONCLUSION

In this work the friction pendulum displacement measurement system is described. The system is going to be installed on the oil-drilling platforms, located close to the Sakhalin Island. The experimental investigations of the system have shown that the system conforms to all the technical characteristics required for such system. The spatial resolution of a few micrometers can be achieved at cost of reduced measurement range. In general, depending on the application, the best system resolution can be approximately estimated as 10^{-4} of the chosen measurement range. The developed system is certified as meteorologically approved measurement device for use in explosive environments and has many other important approval certifications. The planned life-time resource of the system is 30 years.

Without serious modifications such system can be utilized in civil engineering for inspection of the absolute and relative movements of different elements of buildings, bridges, etc. Other areas of system application would be an inspection of the state of large metal constructions, testing of the materials (defining the plasticity limits, breaking thresholds, etc), monitoring the displacements of the geological layers and walls of the mines.

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