LASER-TESTING RIG  2009

Measurement System for evaluation of Shape of concentrating reflector for solar collector Absolicon X10

Master Thesis
Solar Energy Engineering
Reg No:
To my Grandmother Amina.
Her prayers protected me.
*Her belief in me had moved me along the path of gaining knowledge.*

To entire my family.
*Their love and hopes gave me strength.*
Acknowledgement

I would like to express my huge gratitude to my Teacher – Mrs. Eva Lindberg. She confided in me, she taught, she supported and led me along the paths of knowledge.

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ABSTRACT

This Thesis project is a part of the all-round automation of production of concentrating solar PV/T systems Absolicon X10. ABSOLICON Solar Concentrator AB has been invented and started production of the prospective solar concentrated system Absolicon X10. The aims of this Thesis project are designing, assembling, calibrating and putting in operation the automatic measurement system intended to evaluate the shape of concentrating parabolic reflectors.

On the basis of the requirements of the company administration and needs of real production process the operation conditions for the Laser testing rig were formulated. The basic concept to use laser radiation was defined.

At the first step, the complex design of the whole system was made and division on the parts was defined. After the preliminary conducted simulations the function and operation conditions of the all parts were formulated.

At the next steps, the detailed design of all the parts was conducted. Most components were ordered from respective companies. Some of the mechanical components were made in the workshop of the company. All parts of the Laser-testing rig were assembled and tested. Software part, which controls the Laser-testing rig work, was created on the LabVIEW basis. To tune and test software part the special simulator was designed and assembled.

When all parts were assembled in the complete system, the Laser-testing rig was tested, calibrated and tuned.

In the workshop of Absolicon AB, the trial measurements were conducted and Laser-testing rig was installed in the production line at the plant in Soleftea.
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1 INTRODUCTION

1.1 Preface

Solar radiation allows to get thermal energy and electro energy in any suitable place. Direct utilization of the solar energy excludes mechanical parts (turbines and electromechanical generators) and necessity to transfer energy to long distance.

The solar systems, which would be able to produce thermal energy and electricity simultaneously, has usually less specific price per kWh of the obtained energy due to higher efficiency and possibility to use the common structure parts.

Hot water is produced at useful temperatures for such applications as building heating and domestic hot water, as well as many commercial and agricultural applications that require low-grade heat. The motivation for the development of the combination of solar systems (PV/T – Photovoltaic/Thermal) is twofold: in the short term, to produce photovoltaic power and solar-heated water at a cost which is competitive with other renewable energy technologies, and in the longer term, at a cost which is lower than it is possible with current technologies. To achieve this aim, the PV/T collectors must have an inherent advantage over other photovoltaic and thermal technologies.

Most photovoltaic and thermal collectors used for similar applications are flat plate collectors. The most prospective way to reach the competitive efficiency is applying the concentration for the PV/T solar receivers. This technology was named CPV/T – Concentrated Photovoltaic/Thermal. The primary advantage of the CPV/T system is that concentrating light allows having a significant reduction in the area of solar cell coverage, the main cost driver in a flat plate system.

Thermal energy generated could be considered as a byproduct due to the necessity to cool the cells, but in appropriate applications, the thermal energy is equally valuable. A secondary advantage of the CPV/T system is the efficient use of space owing to combining electrical and thermal energy generation, which may be advantageous on rooftops or in other applications where space is limited. The challenge in the development of the CPV/T system is to design a robust collector with a clear pathway to more rapid cost reduction than the incumbent flat plate technology, and to optimize the performance within the cost constraints.
1.2 Background of the problem

The project oriented to create a combined concentrated solar collector was launched in 2002. The project involved around 10 projects at, among others, the Universities in Borlange, Lund, and Uppsala, as well as the Royal Institute of Technology (KTH) in Stockholm.

Absolicon Solar Concentrator was established in 2007 and the first demonstration installations were built in Sweden and Germany.

![Absolicon AB](image)

**Fig. 1 Absolicon AB**

Today Absolicon AB (Fig. 1) is starting the serial production of the most prospective Solar Concentrating System X10. The solar collector X10 produces both electricity and thermal heat in the same module, thanks to the **Double Solar Technology™** [1]

The X10 is a solar collector that simultaneously generates the two forms of energy most used in the daily life: **heat and electricity**. This is possible as it combines a photovoltaic panel and a solar thermal collector in the same module.

It consists of a cylinder-parabolic reflector that concentrates the light of the sun ten times onto the receiver. It is equipped with the latest generation of photovoltaic technology and a **solar tracking system**. For the tracking, special electrical custom-designed high quality linear actuators are used. The objective is to automatically turn the X10 so that the sunlight always is focused onto the cells. The tracking system has a built-in program that automatically protects the photovoltaic cells from being overheated or from storms. If the temperature exceeds a certain value, the X10 automatically turns away the receiver from the sun.

The solar tracking system is controlled by a **PLC control system**, the heart of an X10 installation. Its main function is to ensure that the X10 follows the sun throughout the day. It also includes an integrated web server that allows the remote control of X10 from any computer connected to the Internet.

The X10 can be installed on the ground as much as on a rooftop thanks to its robust construction. The construction is optimized for installations larger than 20m². The X10 is offered in four different lengths; 6, 10, 14 and 18 meters. These different lengths can be linked together in series for installations without any surface restrictions, i.e. everything between 20m² - 100 000 m² is possible to install with the X10.

The basic component of the concentrating system is 2 meters cylinder-parabolic reflector (CPR) (Fig. 2). The CPR consists of the frames, mirror, internal rails and glass cover. The mirror is the steel plate covered with a reflective film for the best reflection. The design of the frame and shape of the mirror were simulated using special software to reach the appropriate shape, which shall be able to provide the concentration of the solar radiation on the receiver.

![Cylinder-parabolic reflector](image)

**Fig. 2 Cylinder-parabolic reflector**
However the final distribution of the radiation on the focal point for the real systems depends on many factors. Digression in production technologies and uncertainty in the using material and chemistry behavior could lead to the improper results.

Figures 3 & 4 show the same concentrated PV/T system from both sides. It is possible to note different improprieties in the design performance. On the upper side the focal line of the mirror is located significantly above the center of the solar cells and the variation of the irradiation density distribution is observed along the receiver. On the lower side the location of the focal line is almost perfect but some variation of the irradiation density distribution is observed, too.

Also it is very important to have valid information about the solar system state after the different kinds of tests. The proper knowledge about after-effects from of different influences helps to improve the system design and production technologies.
For example, Figures 5 shows the extra pressure test procedure. This test is the standard procedure for the solar collectors, which simulates possible snow layer 1 meter deep. Instead of snow, almost 1-ton lead was used to cover the reflector systems surface.

So, according to the reasons mentioned above, it is critically important to create the automatic measurement system, which will be able to evaluate the shape and surface quality with sufficient speed and resolution for any point of the reflector surface. It has to be independent from the weather, to show and keep measured data in handy form.

Fig. 5 The concentrated reflector under the extra pressure testing.
1.3 Project Task

The Project task is to design, develop, calibrate, and put into operation the measurement equipment intended to evaluate the shape and surface quality of the concentrating reflector for the Concentrated PV/T system Absolicon X10.

The methods learning are described in the Section 1.4; consideration of the Absolicon's administration requirements has allowed defining the operation conditions for which the testing rig has to be created.

First, the evaluation process has to be independent from weather conditions that mean it has to have its own source of radiation.

Second, the designed equipment has to be intended to work in the operation conditions of the mass-line production in a big plant. It means that mechanical construction has to be steady to the great workloads. Also, the measurement and automation components have to be steady to all kinds of disturbances, which could exist in the process.

Third, the designed equipment has to be fully automated and easy in operation to work under control of the personal with low qualification [user-friendly]. It means an easy procedure of installation/ removing the tested reflector and easy procedures of the system control. Also, the system has to have safeguards to prevent damaging the tested reflector and rig’s construction in case of improper operation.

Fourth, the obtained information has to be in the form, which is sufficient for the computer processing and storing.

Fifth, the continuance of a single test has to be less then 20 minutes between the reflector installation and its removing from the Testing rig. During this time the construction has to provide resolution of the measured points not less then one measurement line per one centimeter in longitudinal direction (at least 200 lines) and one measurement per two centimeter in direction transverse to the main axis of the reflector.
1.4 Literature Survey (Existing Methods)

The first attempt to create special equipment to estimate the performance of the CPV/T system was made in Australia in 2004. In the framework of the research work, which was conducted at the Australian National University, a device, known as the ‘Skywalker’ module, was designed and built for measuring the illumination flux profile along the focus of a receiver. [2].

The Skywalker module consists of a calibrated concentrator solar cell mounted on an aluminum block and encapsulated with silicone and glass. The short circuit current of the solar cell is measured across a resistor, mounted on the back of the block. Water flows through channels milled into the block to keep the cell at a consistent temperature, which is measured by a thermocouple mounted in the aluminum behind the cell. Using results from the solar cell calibration, the radiation flux intensity at the cell can be calculated. The block is mounted on a trolley that is moved along the focal line of the collector by a motor and pulley system (Fig. 6).

For the evaluation the performance of the first CPRs, which were assembled at Absolicon Company, the next simple device with row shading (Fig. 7) was designed [3].

By putting a screen with a row of horizontal slits on top of the trough in a plane perpendicular to the sun and holding a piece of cardboard on the side of the concentrated mirror, a ray pattern will occur on the cardboard and visualize the path of the rays. The ray pattern is photographed and the analysis will show where on the receiver the focal point is. It also shows which part of the parabola reflects light to the focal point and receiver. By studying how much light is reflected onto the receiver, the reflector shape can be evaluated.

However the measurement procedure depends on the solar radiation availability. For the estimation of the production quality independently on the weather conditions the next simple laser device was implemented (Fig. 8) On the top of the concentrated reflector across the central axe, the rail with small carriage is installed. The laser is fastened on the carriage. Laser irradiates the mirror and can move along the rail. Moving the laser along the rail...
and the rail along the central axe the operator looks on the screen on the receiver and manually records the measurement results.

All these methods are not suitable for the mass-line production process. “Skywalker“ can estimate the common irradiation density on the focal line but cannot reveal the possible fault’s place on the mirror. Another disadvantage is working under direct solar radiation. The second device cannot estimate the reflectors in its real size (2 meters) and also depends on the weather conditions. The latter method is labor-intensive and cannot provide high resolution and computer handling of the obtained data.

Fig. 8 The simple laser device
2 LASER-TESTING RIG ARCHITECTURE AND DESIGN

2.1 Generic description

All testing systems are based on the artificial simulation of the working conditions for the tested equipment. The better we can repeat the future-working environment, the more precisely we can predict the equipment’s behaviour.

For the solar systems it is critically important to provide the artificial irradiation, which would be similar to solar irradiation. (Fig. 9) For the systems, which estimate the geometric properties of the concentrating systems, the most important is to achieve the parallelism of the incident beams. The best tool there is laser. Currently exist number different kinds of laser. They are cheap, small, easy controllable and have a very fast response for the input signal. (Fig. 10)

So, the final solution is to simulate the solar beams by laser beams from the row of lasers installed in lines. The maximum resolution is defined by the size of the laser module. In our case, we could achieve the resolution of one laser beam per 20 mm in the transverse direction and put 48 lasers in line. The resolution in longitudinal direction is defined by the minimum size of the step of the driving shaft. The existing combination engine/driving shaft allows reaching the step size of 2 mm. However, high resolution can decrease the measurement speed because it is provided by mechanical components, which have relatively low working speed. To reach the compromise the next solution was found. The software part of the measurement system includes the selective option, which allows tuning resolution from the User Interface.

To obtain the information about the irradiation density distribution the measurement head was composed from five sensors (Fig. 11). Three of them are located on the solar cell place, one above and one below it. This sensors combination allows getting clear understanding the reflection capacity of every point of the concentrated reflector.

The operation conditions of the lasers and conditions are presented in 1.3.Project Task; they have helped to define the boundary conditions of the Testing rig construction and have allowed conducting the complex preliminary design of the future system.
2.2 Preliminary design and simulation

At the first period under circumstance, which were presented in 1.3.Project task and 2.1.Generic Description, the preliminary complex design was conducted. The constituent parts were defined including their operation conditions and interrelationship.

To help look on the future construction of the testing rig computer simulation of the reflected properties of the laser beam from the reflective surface and 3D modeling of the mechanical design were conducted (Fig. 12). The preliminary design of the software part based on LabVIEW was created.

To test the created software the special electronic simulator was assembled. The simulator allows to give signal similar to the sensors signal and to show the DAQ NI6501 output’s state.

The results obtained during the previously conducted designing and testing were considered. The main options of the future construction of the testing rig correspond to the project’s task and real equipment was designed and created.

The complex approach, which includes the simultaneous design of the mechanical, electromechanical, electronic, and software parts, has allowed creating a reliable and easy-to use device.

So, the testing rig consists of the following main parts:

-Mechanical part, which consists of the basic frame with guardrails, the carriage on wheels moving along these rails and the docking device, which is intended to connect the measurement system with the internal rail of the reflector

-Electromechanical part, which consists of the DC-engine, driving shaft with driving device and sensors which track and restrict the carriage movement

-Electronic part, which in its turn consists of four subparts – measurement circuit, lasers control circuit, engine control circuit and power supply with protection circuit

-Software part, which was created on the LabVIEW basis and provided the general control, collecting and processing the obtained data.
2.3 Mechanical Part

2.3.1 Introduction

The engineering requirements for any equipment for mass-line production include the following specifications. Every device, which takes place in the mass-line production, has to be reliable and robust to external influences. If possible, it has to work without frequent tuning, includes the special security mechanisms to safe the device from improper actions from the personnel, be easy in using and in service. The firmness of the mechanical construction provides the stability of the measurement characteristics of the calibrated and tuned sensors.

The mechanical construction was created from aluminium profiles and components from the Bosh Rexton Company. Bosh Rexton Company produce the very well developed nomenclature of aluminium profiles of different sizes and all necessary components, which allow to create very complicated and advanced construction. One of the main advantages is that these components enable to assemble steady construction, which provides stability for the whole system and at the same time has some potential for easy reconfiguration if it would be need for the production (Fig. 13).

If in future the dimensions and shape of the tested production would be changed, it is possible to make relatively easy the reconfiguration of the construction and to adjust it to the new requirements.

The mechanical construction includes the basic frame, the carriage and the docking device. (Fig. 14).

Fig. 13 General view with and without installed reflector
2.3.2 Basic Frame

The carcass of the basic frame consists of the two lateral crosstops the upper ones of which are the driving rails for the carriage wheels. On these crosstops, the vertical frame is mounted. The vertical frame contains 48 laser modules and laser modules control circuits. On the middle horizontal crosstop, the vertical measurement tower is mounted. On the top of the measurement tower, the measurement head is fastened. The measurement head consists of the photo sensors (the pieces of the solar cell) and amplification circuit. On the one end of the basic frame, also the box with electronic control system, electromechanical part members (sensors, motor and etc.), power supply, emergency switch and stanchion for the computer are installed (Fig. 17). The basic frame has six feet, which are easy retargeted to provide the proper horizontal installation for the whole rig construction (Fig. 16).
2.3.3 Carriage

The carriage is the frame of aluminum profiles; the construction is intended to put and remove the measured concentrating reflector (hereinafter – “Reflector”) easily. The carriage has six wheels to move on the driving rails of the basic frame (Fig.18).

The mirror installation position is located on the distance from the measurement starting point to prevent accidental damage to the vertical frame with the lasers and the measurement tower.

Fig. 17 Basic frame components

Fig. 18 The measured mirror installation procedure
2.3.4 Docking Device.

The docking device (Fig. 19) is intended to provide proper location and move the measurement head on the measurement position and to safety remove it from the reflector after test.

The reflector has the small internal rail on which the PV/T receivers are installed. The mechanical design of the combination carriage/basic frame is specially intended for using this rail for the following of the measurements tower. This combination provides the photo sensors location similar to the PV/T receiver in reflector. Generally it allows for obtaining the information of the reflected beams distribution exactly in the same place where the solar cells are located. The main task in the docking device design was to create a construction, which would be able to automatically put the measurement tower on the internal trough rail, provide the tower a proper moving and safe remove it from the reflector when the test is completed. The problem is that the reflector internal rail's start position could have significant uncertainty in its location. The construction of the docking device was designed to provide the proper installation of the measurement tower on the necessary position even through the rail's start edge has several centimeters deviation in vertical and in horizontal directions (Fig. 20 - 21).

Fig. 19 Docking device

Fig. 20 The guide rib.

Fig. 21 Vertical sinking provides the proper installation in case of the vertical deviation of the rail start position.
2.4 Electromechanical Part

2.4.1 Introduction.
The electromechanical part moves the reflector and defines the measuring point.

The electromechanical part includes the moving system of DC-motor, gear driving shaft, and electrical circuits of sensors. The electrical circuit of the electromechanical part is presented in Fig. 22.

2.4.2 Moving System.
The DC-motor is connected to the gear (Fig. 23), which decreases the rotation speed of the driving shaft to the necessary level and increases the driving force to provide movement of the carriage with installed reflector. The carriage is connected to the driving shaft by special driving device (Fig. 24).

In consequence of the significant length of the driving shaft on free state is sagged. To prevent it, the driving shaft was previously stretched using the special strainer (Fig. 25). The stretching has allowed for making driving shaft straight and decreasing the load on bearings of the driving device.
2.4.3 Sensors.

On the basic frame, three mechanical sensors are installed. The first one defines the mirror installation position (Fig. 26); the second (Fig. 28) and the third (Fig. 27) sensors define respectively start and finish points of the measurement distance.

The first and the third sensors are located on the outermost sides of the moving distance and have additional contacts to break the motor feeding line for the immediate stop of the carriage movement to prevent the testing rig’s construction damaging.

The round blind with the hole is fastened on the driving shaft. The rotated blind is located between the IR-diode and phototransistor, of the optic sensor (Fig. 29). When the hole on the blind crosses the line between the IR-diode and phototransistor the optic sensor generates a signal. It means that the software gets information about every rotation step of the driving shaft. One rotation step moves the carriage two millimeters. It is the minimum possible measurement step, which provides the maximum resolution. The user has an opportunity to change the resolution and, respectively to change the speed depending on the measurement aim.
2.5 Electronic Part

2.5.1 Introduction.

The electronics part is intended to control the laser modules and motor, collect and preliminary amplify the signal from recording the movement and photo sensors and provide communication between electromechanical part and software part which is installed on the main PC (Fig. 30).

The electronics part consists of NI USB-6501, lasers control system, measurement head and power supply with protection circuit.

Most of the components of the electronic part are located in the special box (Fig. 31). The measurement circuit is installed into the measurement head. Also in this box, the motor driver is installed.
2.5.2 NI USB-6501.

The heart of the electronics part is the National Instruments USB-6501 data acquisition (DAQ) device.

National Instruments (NI) offers the complete solutions for the PC-based measurement and control systems. The main idea of the hardware-software complex from the NI is relief engineer-designers from the exhausting work to write the low level codes for equipment drivers and user interface.

Fig. 32 NI USB-6501

At the designing stage, it was found out that laser-testing rig has to evaluate the ability of the concentrated mirror system to forward the incident radiation to the receiver surface. The electronic part of the laser-testing system amplifies, filters, and transforms the obtained data into the digital form. Therefore, the electromechanical part also is managed using the digital signal only. All communications between electronics, electromechanical and software parts occur in digital form. It means that for the DAQ equipment in the laser-testing rig it is enough to have digital input/output only.

So, for the laser-testing rig the NI USB-6501 was chosen (Fig. 32). The NI USB-6501 is a full-speed USB 2.0 device that provides 24 DIO (Digital Input/Output) channels and a 32-bit counter. It means that the NI USB-6501 has 24 single-ended digital lines, P0.<0..7>, P1.<0..7>, and P2.<0..7>, which comprise the three DIO ports. P2.7/PFI 0 can also function as a 32-bit counter (Fig.32). Each of the NI USB-6501 DIO lines can be individually programmed as a static DI or DO line. You can use static DIO lines to monitor or control digital signals. All samples of static DI lines and updates of DO lines are software-timed [4].
Digital I/O
Number of lines
P0.<0..7>------------------------------- 8
P1.<0..7>------------------------------- 8
P2.<0..7>------------------------------- 8

Direction control ........ Input or output,
software-selectable
Output driver type .......Active drive (push-pull)
or open collector
(open-drain), software selectable
Pull-up resistor .......... 4.7 kΩ Vbus
(nominally 5 V)
Absolute voltage range .......... –0.5 to 5.8 V
with respect to
GND
Power-on state ............ Input (high impedance)

2.5.3 Lasers Control System.

The main purpose of the laser control system is to distribute the control signal
from the DAQ NI6501 and provide switching-on the specific laser in the necessary time.

For the laser control the NI6501 has six outputs, which can in binary code
provide control of up to 64 devices. The laser control system has to transform
the signal from binary code to NI6501 outputs to the switch on/off signal for
the appropriate laser.

All lasers were divided into six
groups with eight lasers per group. The first
demultiplexer DM1, using three
high-order bits of the address code on
the NI6501 outputs, provides control over groups of the laser, the second one using, the lower three bits provide control over each laser within every group (Fig. 34).

Physically, the control process is realized into the six drivers. The demultiplexer DM1 turns switch drivers and the second demultiplexer DM2 turns switch lasers into the drivers. As the code 000000 could correspond to the address of the first laser, it could lead to the uncontrolled switching-on the first laser when the software starts working and all outputs are established in 0 state. To avoid this situation, the demultiplexer DM1 starts working from the second output that corresponds to the code 100 on its input. In general it means that the first laser would be switched on if on NI6501 outputs would be established code 000100. Testing rig’s software provides this state for the laser start working and it allows avoiding uncontrollable lasers’ switching on.

The special loop in the software part provides the consecutive transmission of lasers addresses on the output of NI6501 in binary code and laser control system switching on the respective laser (Fig. 35).

Under circumstance of a big power load on the laser, the control system is fed by special separate line at +5 Volt, which is provided by the power supply of the testing rig (Fig. 33).

2.5.4 Measurement Head.

The measurement head is installed on the measurement tower and consists of the special enclosure, ten photo sensors and the measurement circuit.

Five photo sensors are located on each side of the measurement head to provide measurements from both sides of the reflector (Fig. 36). Three of five are located on the same place where the solar cell is located in the real solar system. Additional two cells (one above and one under the main area) are intended to observe the reflected beams’ behaviour outside of the main area. To decrease the influences of the surrounding illumination, the red glass filters are used. The filters are fastened by special tapes, which provide the photo sensors closure to protect them from possible contamination.

In general the whole measurement head and tower constructions provide the location of the photo sensors relatively the reflector similar to a solar cell in a real solar system (Fig. 37-38).
The measurement head and tower construction have potentiality to re-adjust the measurement head location to reach its proper location.

The board with the measurement circuit is located on the upper part of the enclosure. On the back wall of the enclosure, the special hole is made to provide online calibration of the measurement circuit sensitivity.

The measurement circuit (Fig.39) consists of five identical channels and the sensitivity adjusting part. The design of every channel is intended to amplify the signal from the photo sensor when the reflected beam reached it and cut off the constant component from the surrounding illumination. Also it can significantly decrease the 50 Hz components from the illumination with the luminescent lamp. Amplified and filtered on the first stage signal comes in the input of the comparator. In the second input comes voltage level from the sensitivity adjustment part, which defines the sensitivity of the measurement circuit. If the signal from amplifier exceeds the level, which is set by the sensitivity adjustment part it would be transferred in the digital form (+5 V, or 1 in the binary meaning) and from the output of the measurement head would be transmitted on the correspondent NI6501 input.

Pairs of photo sensors, which are located at the same level on both sides of the measurement head are combined and connected to the correspondent amplification-filtering channel. It becomes possible because at any time only one laser can work and software part knows from which side it happens. So, the number of the laser, which irradiated beam and information from the photo sensors allow defining from which part of the mirror the reflected beam is coming. This solution has allowed for fewer components in the measurement circuit.
2.5.5 Power supply with the protection circuit.

Two power supplies are used to feed the testing rig. The first is the specific power supply for the testing rig’s PC (Dell laptop). The second for the feeding the motor, motor driver and the laser control system. The measurement circuit is fed by the +5 Volt line from the NI6501 through the USB connection from the laptop.

The additional components, which provide a stable +5 Volts level for the laser control system, were assembled on the special board together with a protection circuit.

The protection circuit is intended to provide the safety-operating mode after connection the power supplies to the feeding line. The fact is that NI6501 outputs are established on the high level (+5 V, or 1 in binary meaning) when NI6501 is connected to the power (through the USB lines). For some devices in the testing rig (especially for the motor) this state is a command for the work start. It was very important to avoid the uncontrollable switching of the motor and accidental damaging of the installed reflector and components of the testing rig’s construction.

The protection circuit disconnects the feeding of the testing rig when the power supply starts working. The +12 V from the power supply reaches the transistor base through the limiting resistor and open transistor. The relay on the transistor's collector starts working and disconnects the feeding of the testing rig. The protection circuit's design is intended to switch on the relay in cases when +5 Volts on the transistor base (the start state of the NI6501 outputs) or if the transistor base is disconnected. All these precautions enable to have only operating modes controllable by software part. When the software starts working, the state 0 would be established and the testing rig would be fed (Fig. 40).

The second precaution is the special emergency stop button (Fig. 41). This button provides immediate disconnection of all power suppliers from the feeding voltage (220 V). It is necessary for the unpredictable events with the testing rig’s construction and with the operating personal.

However, the laptop has its own battery which provide power supply for the NI6501, which receives signal from the second pair of the contacts into the emergency stop button and provides correct termination of the software's work.
2.6 Software Part

2.6.1 LabVIEW Overview.

To implement the measurement project the LabVIEW software was chosen. As it was noted in the electronics part, National Instruments offers the wide nomenclature of the hardware-software solutions for the measurements and control system. In addition the external DAQ equipment from NI is possible to use with other software environment both from NI and other companies. For example, it is possible to create the system on C+, BASIC and LabWindows/CVI. However, LabVIEW is different from those applications in one important aspect. Other programming systems use text-based languages to create lines of code, while LabVIEW uses a graphical programming language, G, to create programs in block diagram form.

2.6.2 Virtual instruments

LabVIEW includes libraries of functions and development tools designed specifically for instrument control. LabVIEW also contains libraries of functions and development tools for data acquisition. LabVIEW programs are called virtual instruments (VIs) because their appearance and operation imitate actual instruments. However, they are analogous to functions from conventional language programs. VIs have both an interactive user interface and a source code equivalent, and accept parameters from higher-level VIs. There are the main three VI features:

- VIs contain an interactive user interface, which is called the front panel, because it simulates the panel of a physical instrument. The front panel can contain knobs, push buttons, graphs, and other controls and indicators. The data are input using a keyboard and mouse and the results are viewed on the computer screen.

- VIs receive instructions from a block diagram, which are constructed in G. The block diagram supplies a pictorial solution to a programming problem. The block diagram contains the source code for the VI.

- VIs use a hierarchical and modular structure. They are used as top-level programs, or as subprograms within other programs or subprograms. A VI within another VI is called a subVI. An application is divided into a series of tasks, which in its turn could be divided again until a complicated application becomes a series of simple subtasks. VIs are built to accomplish each subtask then combined on another block diagram to accomplish the larger task. Finally, the top-level VI contains a collection of subVIs that represent application functions [5].

2.6.3 Data Acquisition

The fundamental task of all measurement systems is the measurement and/or generation of real-world physical signals. Measurement devices help to acquire, analyze, and present the taken measurements.

Through data acquisition, measurement system acquires and converts physical signals, such as voltage, current, pressure, resistance, sound, light, and temperature, into digital formats and transfers them into computer. Popular methods for acquiring data include plug-in DAQ and instrument devices, GPIB instruments, PXI (PCI extensions for Instrumentation) instruments, RS-232 instruments and last years USB-instruments. Through data analysis, raw data are transformed into meaningful information by using curve fitting, statistical analysis, frequency response, or other numerical operations. Through data presentation, data are displayed in a graph, thermometer, table, or other visual display.

The main discrepancy of DAQ measurement systems from other measurement systems is that the software installed on a computer performs the actual measurements. The DAQ device only converts the incoming signal into a digital signal the computer can use. This means that the same DAQ device can perform a multitude of measurements.
simply by changing the software application that reads the data. In addition to acquiring the data, the application for a DAQ measurement system also uses the software that processes the data and displays the results. Although this flexibility allows you to have one hardware device for many types of measurements, you must spend more time developing the different applications for the different types of measurements. LabVIEW includes many acquisition and analysis functions to help you develop different applications.

The computer receives raw data through the DAQ device. The written application presents and manipulates the raw data in a form the user can understand. The software also controls the DAQ system by commanding the DAQ device when and from which channels to acquire data. Typically, DAQ software includes drivers and application software. Drivers are unique to the device or type of device and include the set of commands the device accepts. Application software, such as LabVIEW, sends the drivers commands, such as acquire and return a thermocouple reading. The application software also displays and analyzes the acquired data.

NI-DAQmx is the latest NI-DAQ driver with new VIs, functions, and development tools for controlling measurement devices. The advantages of NI-DAQmx over previous versions of NI-DAQ include the DAQ Assistant for configuring channels and measurement tasks for a device; increased performance, including faster single-point analog I/O and multithreading; and a simpler API for creating DAQ applications using fewer functions and VIs than earlier versions of NI-DAQ [6].

To conduct the measurements and control in the laser-testing rig the latest version DAQ-mx 8.8 is used.

2.6.4 Simulator

During the test process the software part has to obtain data from sensors and send control signals to the actuators through the DAQ NI6501. Development of the software part was conducted in parallel with all other parts and it was very important to have on-line information about states on the outputs and simulate signals on the inputs of the NI6501.

To have possibility to estimate the work capacity of the software part special simulator was designed (Fig.42).

The simulator has 24 digital inputs (composed in three ports), 24 digital outputs (also composed in three ports), two analogue outputs and pin area, which allows to assemble simple electronic circuit.

The simulator was used to test the outputs of the NI6501 and put signal on the inputs accordingly the logic of action of the software part. Also some components of the electronic part were assembled on the pin area to test their communications with the software part.

The simulator could significantly improve the designing process of the software and electronic parts.
2.6.5 Algorithm of the Software part.

The testing rig’s software includes several main steps (Fig. 43) As it was mentioned above, the DAQ NI6501 at the power supply switching on puts high level (1) on all the outputs. To avoid uncontrollable working of the all components the protection circuit keeps the feeding of the system disconnected while the low level (0) is not put on its input and Software part could control the system.

So at the first step, the low level (0) is been written on all outputs. At the next step, the user interface starts to work (Fig. 44). There the user could define some options of the forthcoming test.

The main format, in which the output data has to be presented, is the numerical table format. However, the user can set option to present data in JPEG format, too, using the button IMAGE. Also it is possible to choose the measurement with or without additional filtering by the button FILTER. As it would be pointed later, this filter allows passing insignificant faults on the mirror’s surface, which do not affect the optical geometry.

Also during the test, it is possible to interrupt temporary the testing procedure and after continue it using the button PAUSE.

Button STOP stops the test and the program automatically moves the carriage to the start position without the data storage.
Triggering the button EXIT leads to finishing the tests and exit from the software part.

A small screen on the top of the user interface allows observing the obtained data just after test finished without using the special software (Excel or Photo editor).

After the test’s options were selected, the button START begins the test procedure. During the movement of the carriage along the measurement distance, the program scans the sensors state and controls the laser and motor switching on/off. At the every measurement step the program composes the array from the results of the measurements and in the end transfer it into the numeric format and/or the image format. The carriage is automatically returned to the start position where the tested reflector could be removed and the next test could be conducted.

A special utility is responsible for the emergency stop input state scanning. If the emergency button was pressed and Testing rig was disconnected from power supply, the program would finish testing procedure in the emergency way with safety arrangement of all outputs of the DAQ NI6501 to avoid the accidental uncontrollable operation after the power supply recovery.

2.6.6 Data Presentation

For the data presentation it was determined that the software has to convert the obtained from the photo sensors data into two forms – table and map as image. The table form is useful for the data storage and processing because it has relatively small size and allows calculating the percentage of the irradiated cells. But for the more vivid estimation the image map is more suitable.

So, as there are five photo sensors, there could be 32 combinations of the irradiated sensors. In the table form, they could be presented as figures from 0 up to 31. (Fig. 45)

![Fig. 45 The correspondence of the illuminated photo sensors to the location and color of the highlighted cells in the data map and to the figures in the table, respectively](image)

31
16
12
6
4
0

Fig. 45 The correspondence of the illuminated photo sensors to the location and color of the highlighted cells in the data map and to the figures in the table, respectively
3 CALIBRATION

3.1 Laser alignment

To reach the similarity in the beam geometry for proper simulation of the solar radiation is very important to forward laser beams strictly transversely to the glass cover of the reflector and in parallel to each other. The mechanical design of the rig’s construction provides the proper reciprocal parallel location the of glass cover of the installed in the carriage reflector and the laser shelf (Fig. 46).

For the laser beam alignment, the targeting method was chosen. In the lower part of the laser frame, the additional calibration shelf is installed (Fig. 47).

The holes in the calibration shelf are used as a mark for the laser targeting. In the calibration shelf, 48 holes were drilled opposite each laser. All members of the laser frame (also most members of the testing rig's construction) were cut on the Bosh Rextroth plant with high precision that provided very accurate reciprocal location of all construction members. Every laser has to be targeted on its own hole, which was drilled in the same distance.

To provide the proper fastening and long stable operation, every laser is fastened using four screws and covered with the special glue (after finishing the calibration procedure for all lasers) (Fig. 48).
The special device was used to target the laser beam (Fig. 49). This device could provide the precision inclination in two perpendicular directions.

The alignment procedure includes the next steps (Fig. 50):

- Laser installation on the laser shelf, there the laser is connected to the battery
- Alignment device installation, manual rough targeting and strong attachment of the device to the laser shelf
- The precise alignment is reached by rotation of the screws on the device which provides laser inclination in the perpendicular direction
- The adjusted laser is fastened on the laser shelf by its own four screws
- The alignment device is removed
- The laser is adjusted
All lasers were adjusted in series and after that they were covered with a thermo glue to avoid self-loosening under circumstance of the whole construction vibration. After the alignment, the lasers were connected to the circuit (Fig. 51).

The software part includes the special utility intended for the periodical testing the lasers beam location. This utility provides fast switching on/off for the all the laser in series that gives an opportunity to observe all lasers’ beam location.

### 3.2 Measurement head’s sensitivity calibration

As it was pointed in 2.4.4, the measurement circuit has the option to change sensitivity. Operation conditions of a measurement system depend on the environment illumination, its level and characteristics, and reflection surface condition.

During the production process it was tried to keep the plastic protection cover, which protects the mirror surface from the accidental scratching. Usually this cover is removed on the operation site just before the whole solar system assembling. At the first step of designing Absolicon AB administration asked to create a testing rig, which would be able to work through this cover. From this point of view, the amplification part of the measurement circuit was designed with a high amplification rate and sensitivity. However, in the reflector production process of the protection cover is partially removed (Fig. 52) and in these areas, the reflected beam usually is destroyed totally and cannot reach the photocells.

The first trial measurements have shown that the measurement circuit can work with a beam reflected from the protection cover but another problem was found. The reflection abilities of the reflector with and without protection cover differ significantly. The protection cover distorts the shape and location of the reflected beam and leads to the wrong estimation of the reflector’s ability to collect the solar radiation on the main receiver.

![Fig. 51 Adjusted and connected lasers.](image)

![Fig. 52 Protection cover](image)
area. It has become the serious reason to refuse from the protection cover keeping. It was decided that reflectors have to pass tests without protection cover.

Refusal from the protection cover has allowed decreasing the measurement circuit sensitivity. During the same trial measurement it was also decided that extra sensitivity made the circuit liable to the disturbances from irradiation of the luminescent lamps. The operation frequency of the measurement circuit is close to the operation frequency of these lamps (around 50 Hz). The filtering part of the circuit can effectively cut the constant constituent of the irradiation (for instance, the solar irradiation) but cannot eliminate totally the variable constituent from luminescent lamps. Decreasing the sensitivity could solve this problem.

At the first design steps, the ability to conduct online calibration was integrated in the measurement head construction. It is possible to do it by rotation of the variable resistor node through the hole in the case’s wall of the measurement head (Fig. 53).

For the calibration of the measurement of the circuit sensitivity, the second additional utility is used. It allows observing the state of all the photo sensors’ output. There are two options – with laser switching on/off in series and without it.

It is very important to switch on all environment lights, which would correspond the normal operation conditions with reaching the normal illumination on the operation site. The measurement head has to be input in the mirror with appropriate surface quality to obtain the laser beam reflection.

At the first step, the calibration utility has to work without laser irradiation. Rotate the variable resistor to reach the amplification level when the photo sensors react to the environment illumination – a signal appears on any of the photo sensors’ output. After that, it is necessary to decrease the amplification to eliminate output signal from surrounding illumination.

At the second step, the lasers have to be switched on. After that, it is necessary to decrease the sensitivity till the signal from the reflected beam on the photo sensors cannot be measured. During this procedure, it is very important to calculate how many rotations were done.

At the third step, the sensitivity has to be increased again. It is necessary to make the half number of rotations done at the second step.

So, after all these steps the sensitivity would be set at the middle level between the level where disturbances from surrounding illumination could affect the measurement results and the level where the Measurement head could recognize the response from the proper surface of the reflector.
4 Measurements

4.1 Introduction

The testing rig is a complicated measurement system, which was designed for the specific purpose. It consists of the parts, which were created specially to solve the specific task of evaluating the quality of the surface and shape of the concentrated parabolic reflectors for the CPV/T solar systems. All parts are unique and do not have any prototype. The basic idea of the laser measurement issue from the simple device (Fig. 8), which could help evaluate the mirrors during the manual testing.

Such a newly designed system, the testing rig and its parts, could have technological and designing mistakes, which have to be revealed and repaired during the trial measurements. To avoid a number of mistakes and decrease the risk of the unpredictable behavior of the system, all parts were tested separately before assembling into the whole system. To test the various parts several software applets were created. They allowed testing the electromechanical part (the motor controllability and the sensors triggering were tested) and the electronics part (the lasers controllability and beam response from the photo sensors were tested).

The software part was tested using the special simulator, as it was mentioned in Section 2.5.5.

However, the combined work of the all parts could reveal more problems then it was awaited before.

4.2 Trial measurements

The first trial measurements has shown that some components are receptive to the electromagnetic disturbances that has lead to the false triggering of the mechanical sensors and false signals from the photo sensors.

The long wires from sensors and relatively high input resistance of the inputs of the

![Diagram](image)

Sub. VI, which scans the sensors state

- While loop continually scanning the sensor
- Time (ms) between scanning
- Shift register, which keeps the states from previous scanning steps
- The comparison the results of the three consecutive scanning.

Fig. 54 The code area to prevent the sensors false triggering

NI6501 have allowed collecting and putting on inputs the disturbances voltage, which was enough for the false triggering. Since the disturbances are the short (usually less then 100 ms) impulses the solution to improve software was found. In the software the code was implemented, which, conducts the three steps scanning of the sensor state with following comparison (Fig. 54). If all scanning results show the sensor triggering, this action has to be carried out. This code was implemented for all mechanical sensors.
After tuning the electromechanical part the first measurement was conducted. The first image was obtained. (Fig. 55)

The measurement circuit work has shown that it is affected by disturbances, too. However, it could be affected by light disturbances from luminescent lamps and electromagnetic disturbances, too. To separate the influence from different sources the shadowing of the measurement head was conducted.

To eliminate the influence from the electromagnetic disturbances it was enough to make the additional isolation of the amplification PCB boards in the measurement head.

The first test was conducted with the protection cover on both sides of the reflector. Later the cover was removed from the left side to conduct test under the real conditions. The protection cover on the left side was left to estimate the ability of the testing rig to obtain data through the protection cover and as a reference point.

The result of the first test has shown that it is necessary to conduct the whole construction work analysis and more accurate tuning.

There was defined that the work logics of the low-pass filter, which is installed on the measurement circuit’s input to cut out the constant component of the input signal, needs to switch on the laser just after illumination of the respective photo sensor to allow it to reach the zero level. At the beginning lasers were turned switched directly in series. If the same photo sensor was illuminated in row, the input filter could not reach the zero level and did not let pass the next input signal properly. An additional step was introduced into the software to switch-off lasers just after the respective photo sensor has got the response from the reflector.
It has allowed increasing the contrast of the obtained image and significantly improving the test readability. (Fig. 56)

However, the test has shown the traces from the disturbances on the image. As the test was conducted under illumination of the luminescent lamps, it was important to define the origin of the disturbances. The additional tests, in which the measurement head was totally covered by the black paper, revealed that these were the electromagnetic disturbances. As it was mentioned above, the influence of the electromagnetic disturbances was eliminated by additional electrical insulation of the measurement circuit board from the testing rig frame (Fig. 57).

Fig. 56 The test result after the first improvement

The edges of the partially removed protection cover and their trace on the image

The blind (piece of the black paper) is indented to define the origin of the disturbances

Fig. 57 The image after the electromagnetic disturbances influences eliminating

Two blinds which were put to test the sensitivity to the electromagnetic disturbances
At the next step, the protection cover on the left side of the reflector was removed and the test was conducted (Fig. 58).

As it possible to note, the test quality was improved sharply but some small faults on the left side needed the additional investigation because nothing was observed visually on the respective places on the mirror. At the next steps, the mechanical Stop sensor tuning was conducted to eliminate the measurement behind the reflector edge.

The attempt to increase the sensitivity of the measurement circuit has given negligible result but led to the significant increasing in the influence of the luminescent lamp illumination (Fig. 59). In addition, the test with higher sensitivity in the darkness, when the influence of the illumination was eliminated, showed that some faults left on the image. It was assumed that there exists the other cause of the faults.
The proper investigation of the reflector surface was conducted and gave the unexpected effect.

The fact is that the mirror surface of the reflector is manufactured by laminating the special high reflective plastic film on the steel. During the laminating process small air bubbles (around the 2-3 mm) appear, which could lead to the beam dithering (Fig. 60).

To estimate the influence of the bubbles on the reflection the special test was conducted. During this test, single laser irradiated several reflective places and reflected response was obtained on the white screen close to the focal point of the mirror. According to the reference image the reflection from the almost “ideal” reflective surface was obtained. The dimension of the reflected beam from the «ideal» surface corresponds to the dimension of the radiated beam. It is approximately 2x4 mm. It is possible to note that in some cases, the beam dithering was so significant that it was enough to decrease the density power on the photo sensors up to the level which was less then photo sensor triggering level (Fig.61).

In some cases, the response from two or three nearest photo sensors could be obtained (Fig. 62).

Fig. 62 Example of the response on several nearest photo sensors

The response from these small faults could lead to the uncertainty in the calculation of percentage of the defective surface of the reflector. The area of the measured cell on the mirror is approximately 120-200 mm² (20x6-10 mm) and depends on the chosen resolution, whereas the area of the bubble is not more then 3-4 mm². If the beam reaches the bubble and photo sensors get wrong response, the whole area of the measured cell should be taken into account.

To increase reliability of the obtained data, two solutions were offered. First, to increase the sensitivity of the measurement circuit up to the level, which would be enough to receive the response. Second, to implement the pre-processing of the obtained responses; in this case, three measured passes are needed for every measured cell; software
compares responses and chooses which one corresponds to at least two similar ones from three received. Both solutions were tested. Tests were conducted in absolute darkness and under illumination of the luminescent lamps (Fig. 63)

As it is possible to see, the sensitivity increasing partially has allowed avoiding the information losses but it has shown extremely insufficient results under illumination of the luminescent lamps.

The data pre-processing has given better results but the problem related to the light disturbances has remained. It was very difficult to find explanation to the fact why fault areas were shown in different places on the same reflector. Without illumination, results of the tests were sufficient while under illumination every new test gave different image.

The special investigation of the interrelation of the signal from the laser beam and from the illumination of the luminescent lamps on the photo sensors and in the measurement circuit was conducted.

The cause was found to be in the variable phase between the impulses (100 Hz) of the lamp irradiation and the impulses from the laser. Only this factor could determine discrepancies in the test results.

The measurement circuit has the low-pass filter, which is intended to cut the constant component of the surrounding illumination. This filter also decreases the level of the disturbances from the impulse disturbances from the luminescent lamps. However, it leads to the presence of the negative (below the zero voltage level) components of this impulse signal in the pits between the positive components of these impulses. If the reflected beam from laser reached the photo sensors simultaneously with this pit, it could be rejected and could not reach the sensitivity level, especially if the beam was reflected from the place with low quality (Fig. 64)
Illumination from the lamps on the mirror surface 100 Hz

Illumination from the lamps on the photo sensor’s surface. The level of the signal is decreased because of passing through the red glass filter.

Signal from Illumination of the lamps after passing the low-pass filter in the Measurement circuit.

Sensitivity level (defined by the variable resistor on the comparator input).

Laser irradiation on the mirror surface (in darkness without disturbances from lamps).

Laser irradiation on the photo sensors, different level because of the mirror surface’s quality.

Signal from laser beams after passing the low-pass filter in the Measurement circuit.

Scanned data in binary code on the Measurement circuit output/ NI6501 input.

In case, when the environment illumination and light disturbances presence. Combined signal from laser beams and lamp illumination after low-pass filter passing.

In case when laser signal falls into pit between the lamps’ light signal it could be reason to reject a signal because its level would be below the sensitivity level.

Signal was scanned as zero and in the Software part the wrong information was transferred. It leads to the fault place presence on the sensitivity map.

Fig. 64 Signals on the Measurement circuit input/output and reason, which originates the phantom faults.
To avoid the signals losses the following solution was offered. In the software part the additional loop was added, which switches on the laser two times in one measurement cell. The time interval between these switching was selected to be less then the period of the luminescent lamps radiation impulses. The period is 10 ms and the time interval was selected approximately 4-5 ms. It allows to avoid the synchronization with the pits in lamp’s impulses at least for one beam from the irradiated pair (Fig. 65). The software part scans the measurement circuit output twice per measured cell, remembers the value from the first response, conducts the binary addition (operation OR) with response in the current state and after that transfers the obtained result to the next steps of the software part.

On the other hand, the time interval between two lasers beam is small enough to be sure that the measurement was conducted from almost the same place on the mirror. The moving carriage’s velocity is 6 mm/sec. The time interval is 5 ms.; it means that the measured area could only move for 0.03 mm. It is possible to infer that the measurement was conducted from approximately the same place (Fig. 66)
Laser irradiation on the mirror surface (in darkness without disturbances from lamps)

Scanned data in binary code on the measurement circuit output/NI6501 input.

Signal from illumination of the lamps after passing the low-pass filter in the measurement circuit

Sensitivity level (defined by the variable resistor on the comparator input)

Laser irradiation on the mirror surface (in darkness without disturbances from lamps)

Laser irradiation on the photo sensors, different level because of the mirror surface’s quality

Signal from laser beams after passing the low-pass filter in the measurement circuit

Scanned data in binary code on the measurement circuit output/NI6501 input.

Data are transferred to the next steps in software part after operation of the binary addition (operation OR) of the data obtained in the double-scan cycle.

In case, when the environment illumination and light disturbances presence. Combined signal from laser beams and lamp’s illumination after passing low-pass filter. One signal in double-scan cycle is lost and scanned as 0.

Data are transferred to the next steps in software part after operation of the binary addition (operation OR) of the data obtained in the double-scan cycle. Although one reflected beam rejected in common the possible mistake was prevented and in the next step in software part the valid information was transferred.

Fig. 66 Signals on the measurement circuit input/output after the software part was improved.
To test the improvement in software part, the series of the tests was conducted. The measurements were conducted in darkness and under illumination. To test the optical sensitivity of the improved system, several different objects were put on the surface.

From Fig. 67 – 70 it is possible to note that the insertion of the double –scan loop has allowed reaching the significant steadiness of the optical system to the light disturbances from surrounding illumination. At the same time, the sensitivity of the optic system in evaluation of the mirror shape remains sufficient to the operational conditions, which was defined the project’s start.

The main goal of the system is to evaluate the performance of the mirror’s shape. The main reason is impossibility of the visual evaluation of the shape. From this point of view, the filtering system was tuned to pass small surface faults and pay more attention to the optic geometry of the mirror.

The test results (Fig. 69) have shown that testing rig can track even slight variation in the optic geometry. Information about distribution of the reflected beams on the central area of the receiver (where the solar cells are located in the real receivers) as well as the data from sensors above and below the central area allows not only finding out the faults but also evaluating their characteristics. From the color and the distribution of the sub cells on the measurement cell in the sensitivity map, it is possible to know convexity or concavity.

Information, which is obtained on the testing rig, allows observing the behavior of the reflector components, estimating the influences of the different part of the production technology and, especially in the case when something has been changed in production technology, it is very easy to get an image before the changing and just after it and compare the obtained results.

The testing rig becomes the universal tool, which is able, on the one hand to avoid the tiresome work of the manual testing in mass-line production and, on the other hand it is the handy tool for the research works intended to improve the existent construction of the solar systems and to design a new system. It is possible to estimate every step in the designing and production processes.
Fig. 68 Optic sensitivity test (without illumination of the luminescent lamps)

Fig. 69 Optic sensitivity test (under illumination of the luminescent lamps). There is one rectangular reflector is bended to repeat the shape of the mirror’s surface.

Fig. 70 Optic sensitivity test (under illumination of the luminescent lamps). The same objects are located on another place of the mirror.
5 Results and conclusions

5.1 Introduction

During the trial measurements, the proper adjustment of all components of the testing rig was conducted. In most cases, the behavior of the system was close to the options, which were outlined in the project task. However, the significant number of mistakes and unpredictable events were revealed. So, it is a very common situation in designing new equipment. Trial tests have helped to change some components in mechanical part to make the testing rig user-friendlier in operation. Hardware and software upgrades have made the system much more steady to the different kind of disturbances. Also the improvement of the user interface made it intuitive obvious.

After implementing the last improvements in the software part the last version was composed in the install set. This set includes the main program, special calibration utility and drivers, which support the external equipment (there is NI6501). The calibration routine is intended to test the lasers’ beam direction and the photo sensors sensitivity and also to make their calibration. After that the set after was installed on the testing rig’s computer.

As the testing rig is the part of mass-line production, it was moved to the plant in Soleftea. There installation and calibration procedures were conducted and operational personal was taught.

There were tests conducted, some in the real production conditions.

5.2 Site tests’ results

After the installation procedure (Fig.71) the first measurements in real production conditions were conducted. All tests were conducted under illumination of the luminescent lamps because it was impossible to switch them off. However the results of the test have brought out clearly the steadiness of the testing rig to disturbances from environment illumination.

The obtained results (Fig. 72-74) were compared with the results of the hand tests for the same reflectors. The hand tests were conducted in transverse direction with the same resolution (48 points) but in longitudinal direction they have only four line whereas
the testing rig gives information in 333 lines that means the much better resolution. So this comparison is significantly weak. However the common trends were shown clearly and coincided for both kind of test. Of course the accuracy and the test time were significantly better for totally automated Testing rig. Also the obtained date from Testing rig could be easy sent by e-mail and could be stored in computer memory for the following analysis.
To investigate the possible influences from the plastic protection cover on the test results the special test was conducted. For the reflector 231 measurements were conducted with protection layer and without it (Fig. 74). The obtained results show that protection layer can significantly disturb the measurement results. Edges of the protection film do not pass laser beams totally. Also the protection layer corrupts the reflection from the mirror and significantly decreases the accuracy of the measurements. So, the final decision was to test reflectors without protection covering to reach the proper results.

5.3 Conclusions

The tests, which were conducted under the real production conditions, allow for making the following conclusions.

The designed laser-testing rig has shown the operational capabilities, which correspond or exceed the options, which were defined in the project task.

Semiconductor lasers can provide necessary irradiation conditions. Instead of moving one laser in transverse direction (as it was on the simple testing device in Fig. 7. I used a line from 48 lasers. This solution provides sufficient resolution and allows eliminating mechanical components, which is necessary to move one laser along the whole surface.

To reach the fully automatic, proper and easy-conducted testing procedure I developed the mechanical and electromechanical design, which includes the self-moveable carriage. The carriage’s and basic frame’s design provides the reflector’s proper installation and moving under the laser line.

My suggestion was to use LabVIEW as a software platform, which could be used by a designer without great experience in high-level programming. At the same time LabVIEW has all necessary tools to provide control, measurements and transforming the obtained information into a suitable form. It has allowed reaching the sufficient results in relatively short time.

So the created laser-testing rig shows the operational conditions, which corresponds to the parameters, which were defined in Project task or exceed them.

System is fully automated, the testing time less then 11 minutes (in Project task is 20 minutes); state-of-the-art resolution is 333 lines or 2x0.6 cm. (the project task required 200 or 2x1 cm.).
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