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LASER COMPUTER-AIDED SYSTEMS FOR GTE GAS-AIR TRACK ELEMENTS INSPECTION

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Abstract. The technical characteristics, advantages and applications of an automated optoelectronic measuring system for inspection of gas-turbine engine (GTE) element parameters designed by "Optel" company, State Aviation University of Ufa are presented in this paper. The measuring apparatus can be applied for research in industry. Its main advantages are non-contact and high scanning speed.

Key words. GTE, inspection, optoelectronic, measurements, software.

1. INTRODUCTION

While new information technologies developing, design of technical vision computer-aided systems for non-contact measurement of geometrical parameters of complex-shaped objects become more and more vital. At present the important problem in air-engine industry is the design of new GTE with improved characteristics. In this case the problem of inspection and control of air-gas GTE track parameters should be solved. Objects of interest are complex work pieces generated by CAD / CAM technologies, as well as GTE air-gas track. Often such measurements have to be done very rapidly to respond to the specific phase of a fast process. For this purpose optoelectronic methods, which use a laser principle, are of particular interest. They can be applied for universal purposes, are very accurate and efficient and require no contact with the object to be measured.

The labour intensity of GTE manufacturing is largely dependent on labour intensity of gas-air track manufacturing. It includes up to 10-20 rotors and stators (jet) steps, each of which contains up to 100-200 blades. On the whole every GTE contains up to 1000-2000 blades of 20-40 types and sizes. Each gas-air track element requires inspection of many geometrical parameters. That is why inspection means and technologies are considerable part of GTE manufacturing, they influence engine prime cast and define manufacturing preparation period of new GTE.

GTE blades are usually inspected with outdated subjective manual, visual and contact means: templates, optic-mechanical devices for measuring blades, etc. Sometimes the selective control of blade geometry is carried out by contact co-ordinate-Measuring Machines (CMM).

Usually the GTE rotors and stators parameters are inspected by subjective manual and visual means: set of contact measuring devices (templates) and CMM, which frequently deform their blades. Those means have become outdated and do not meet the modern requirements.

The new high-efficiency laser computer-aided "OPTEL" systems of new generation for measurements of complex shaped object geometry with flexible and fast switch to various types and sizes are designed in "OPTEL" company [1 – 4]/. The systems described in this paper can be used for measurement of main element parameters of GTE gas-air track:

a) separate blades and technological equipment for blade producing;
b) disks for blade wheel;
c) mounted blade fence on rotors and stators.

The optimum blade placement in GTE blade fence is also important.

The latest models of “OPTEL” systems allow to carry out the all-inclusive inspection of production stage of manufacturing of GTE gas-air track. It can be done from the beginning of primary part to final inspection of ready GTE blade fence, with database on stages and GTE in whole being created.

“OPTEL” system consists of four basic modules:

1. Hardware-software complex for measurements of blade and technological equipment geometry of various types and sizes. Databases on blade airfoil, root and edge geometry, displacement angles, airfoil profile chords, leading and trailing edge thickness, maximum airfoil profile thickness, airfoil waviness, etc. are created.
2. Software for blade distributions in database on rotors (stators) sets with selection according to blades mounting angle, weight, static moment, etc.
3. Hardware-software complex for non-contact measurements of real parameters of blades mounting in rotors and stators of various types and sizes:
   - Blade mounting (displacement) angle,
   - Critical (throat area) section of a grillwork, etc.
4. Hardware-software complex for non-contact measurements of disks and rotor rings profile.

2. MEASURING PRINCIPLES AND METHODS

Application of triangulation and “shape from shadow” method in combination with electronic and software processing of information signals guarantees high accuracy and efficiency of non-contact measurements, performance reliability in plant conditions.

The principle of the measuring apparatus is based on a non-contact shadow method using a laser scanner. During operation, the object is scanned and the image is projected on a CCD or CMOS array. The generated signals are filtered to eliminate noise; they are digitised and then processed by a computer. A small diameter laser beam is used to obtain a high complexity. The three-dimensional reconstruction is done with the help of software, which also generates other display parameters and documents.

Measurements are non-contact and fast (hundreds thousands times per a second). It allows to carry out practically continuos measurements in relative motion optoelectronic head and item under control.

One of kind of processing is construction of measured surface. For construction of a surface on the real data the method of spline-approximation is used. The spline-function f (P) is defined by the formula

$$f(P) = \sum_{i=1}^{N} a_i g_i(P) + \sum_{k=1}^{q} b_k n_k(P) , \qquad (1)$$

where: $g_i(P) = (k_i(x), G(x, P))$,
a_i, b_i – real factors,
$n_1(P)$, $n_2(P)$,…, $n_q(P)$ – parts of nucleus of the operator of transformation,
N - quantity of points of a approximation grid,
P – approximated point.

The main advantages of the apparatus are non-contact operations, very high speed, high precision, and multi - purpose and wide range of applications, small overall dimensions and low weight.

3. LASER INSPECTION OF GEOMETRY OF SEPARATE BLADE AND TECHNOLOGICAL EQUIPMENT GEOMETRY FOR THE MANUFACTURING

During GTE manufacturing it is necessary to produce compressor and turbine blades and support tools of tens types and sizes. Technological process of blade manufacturing consists of series of various phases (operations), including consecutive processing of work pieces with various tolerance up to finished blade. The number of operations, including subsequent inspection of workpieces geometry, can be from 5 to 10.

Usually inspection is carried out with the help of visual template tools and tools and such tools as CMM. Corresponding template tool is produced for every operation with tolerance change. Measuring accuracy of template tools is equal to 0,03 - 0,05 mm. Resource of template tool is equal to 0,5-2 years. Usually 2-3 template sets are produced for every type and size, which increase cost proportionally. Moreover, contra-templates are needed in addition for inspection of template themselves. The total number of template tools per 1 GTE can reach hundreds sets. Template tools cost reaches from 5000 US$ to 10000US$.

“OPTEL” systems are intended for non-contact measurements of profile and geometrical parameters of practically any complex shaped object, made from various materials, in particular fragile and soft: compressor and turbine GTE blades, press-forms, bars, wax and plaster model equipment and others. With their help manufacturing of new GTE blade fence elements and reconditioning of used ones can be done.

Kinds of measured by “OPTEL” systems items during compressor and turbine blades manufacturing are in fig. 1 and 2.

“OPTEL” system has the following features:

- unique possibility to carry out non-contact fast automated computer-aided measurements of 3D objects;
- automation of labour intensive measurements, removal of subjective factors and guarantee of 100% inspection of important GTE items with result logging in database;
- high efficiency;
- measuring time of 1 section - up to 2 - 5 sec.;
- measuring time of blade airfoil - from 20 sec. (up to 100 blades/hour);
- high resolution - less 0.001- 0.0005 mm;
- high accuracy - error is less than 0,005 - 0,01 mm;
- high versatility: measurement of hundreds items of various types and sizes are carried out in accordance with electronic draft (mathematical model) of item, with conversion time to item of another type and sizes being less than 1 min;
- compatibility with CAD/CAM system ("Unigraphics ", "Cimatron ", "AutoCAD" and others).

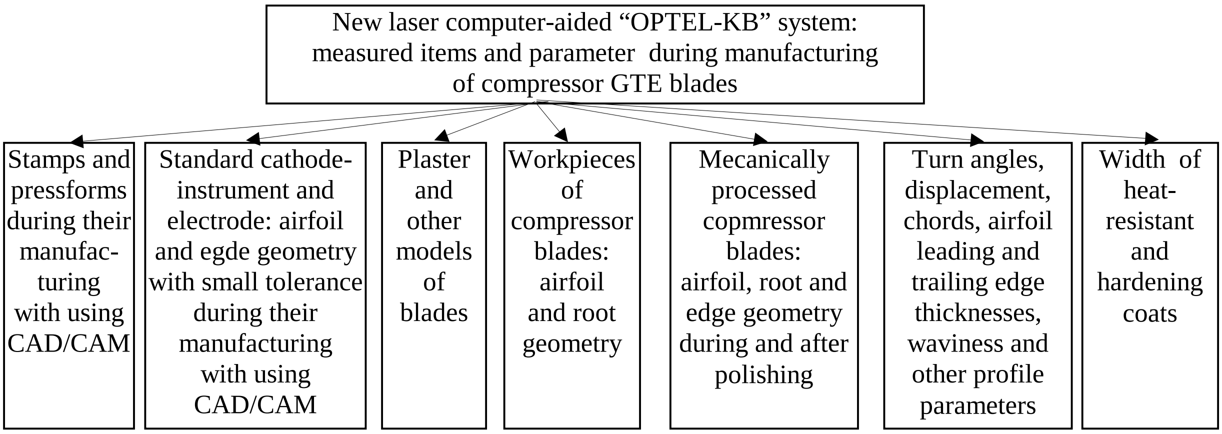

Fig. 1. Application of “OPTEL-KB” systems

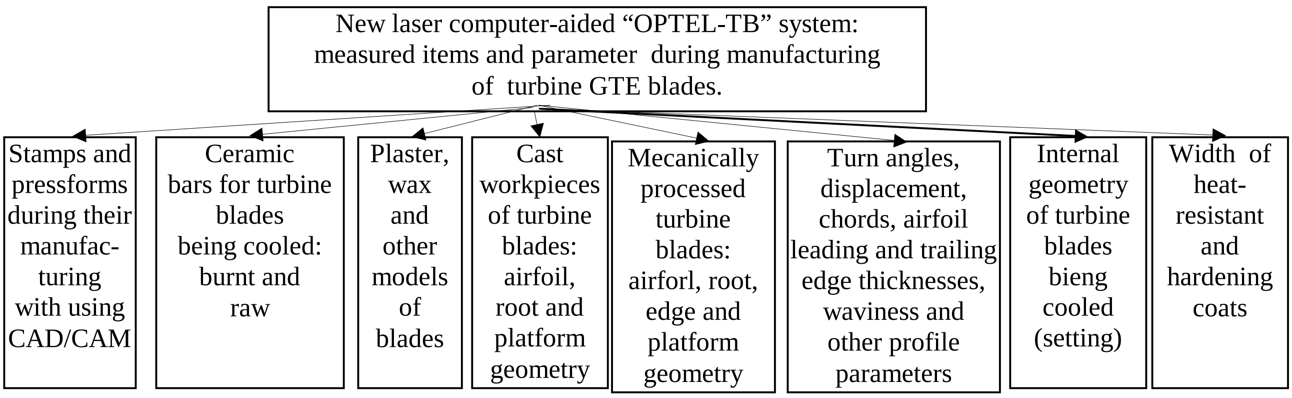

Fig. 2. Application of “OPTEL-TB” systems

High-precision and high-speed “OPTEL” systems, inclusive specific mathematical support and software, carrying out measurement of real dimensions of item profile and their comparison with specified according to draft (mathematical model), with optimisation of displacement and turn angle definition and database creation.

Automated basing according to item co-ordinate axes, depending on given version, can be done by both tool or standard sample base locator and item location surface, for example, blade root or standard points or sections of real profile (for example, for turbine blades: of suction side, pressure side points.).

System software is developed for operating systems MS DOS, Windows 95/98, NT. Systems allows to measure section profile displacement and turn angle, leading and trailing edges shape and radius with displaying them in graphic and text form as well as in a form of file or protocol on paper. Measuring results output to display and printer in a form convenient for user (graphs, tables, measuring protocols, statistical data, reports and others). Measuring results are saved automatically in computer memory, which allows creating database on various items. Moreover, it is possible to carry out recurring measurement and comparison of items after additional influence, in particular, treatment, mechanical loading and trial exploitation.

Required total numbers of used «OPTEL» systems during manufacturing of one GTE are less in 10-20 times than the total numbers of template tools. This is defined by proportionally higher efficiency of inspection with digital registration of results.

The figures 3-7 show the results of fast laser computer-aided measurements 2D and 3D imaging of digitising.

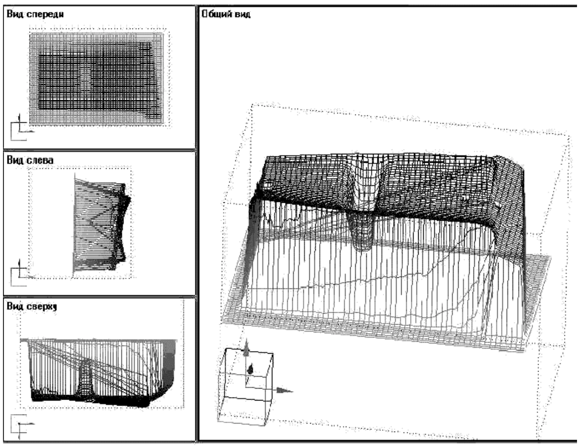

Fig. 3. Results of three-dimensional measurement of stamp profile.

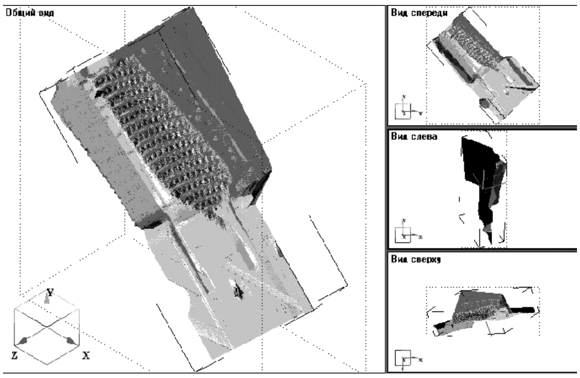

Fig. 4. Results of three-dimensional measurement of press-form profile for producing ceramic blades.

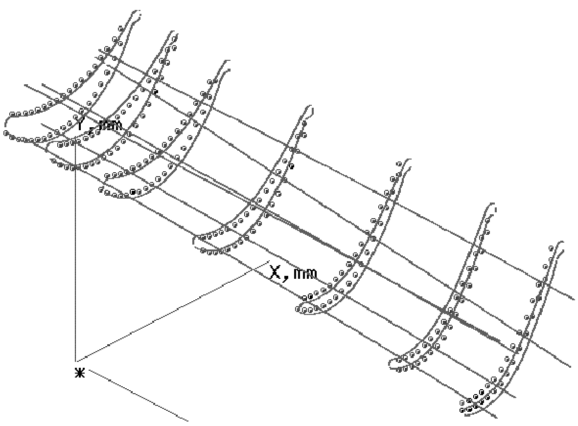

Fig. 5. 3D view of turbine blade profile.

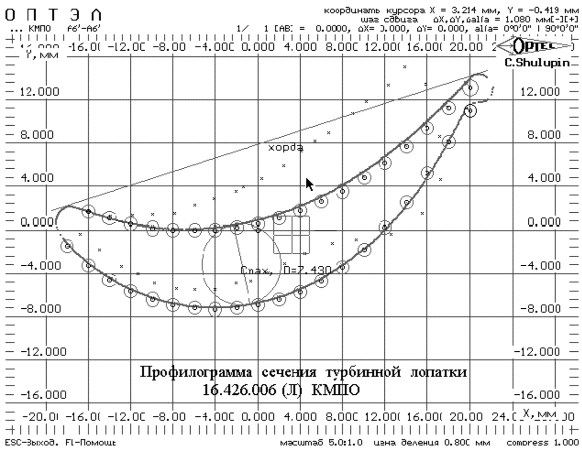

Fig. 6. 2D view of turbine blade section profile with points of drawing.

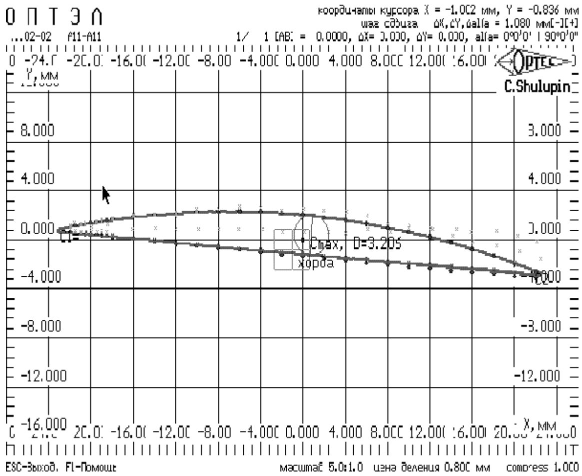

Fig. 7. 2D view of compressor blade section profile with points of drawing .

3.1. Laser inspection of disk parameter for blade wheel

“OPTEL-DISK” system allows carrying out non-contact measurements of GTE disk profile and width. Electronic part of system contains laser optoelectronic head and electronic unit.

Measurements of two surfaces are made simultaneously. To scan the profile, attachment point is placed on carriage, rotating and moving with the aid of intermittent drive.

Measuring process control is made according to specially developed program. Program allows scanning disk with various turn angles, to process, to visualise and to control obtained data, as well as their keeping in database. After every measurement program creates graphic and text protocol (protocol format and template are specified by user) in electronic form and in from of paper printout.

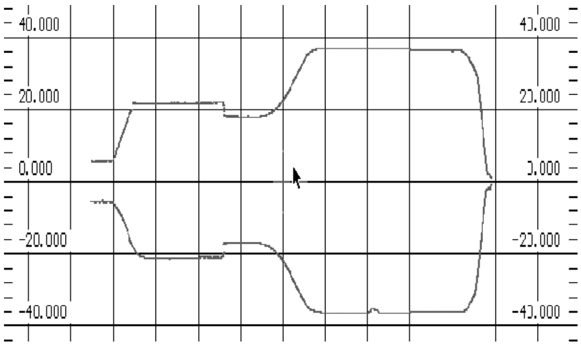

Fig. 8. Disk workpiece profile of GTE blade wheel

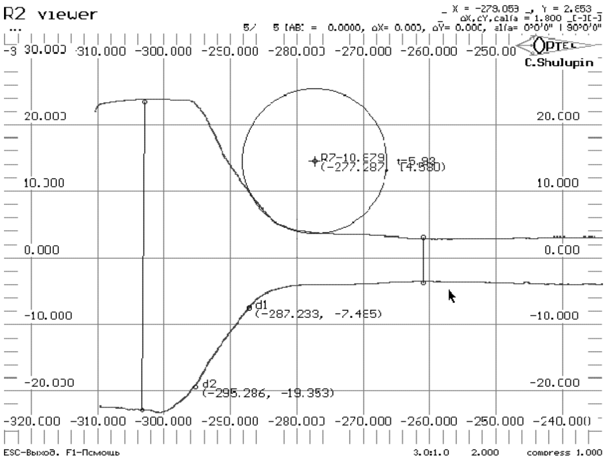

Fig. 10. Path of expanded disk profile with selected parameters: thickness, lengths and radiuses of rounding.

3.2. Laser inspection of parameters of blade mounting in blade fence

Automated "OPTEL-GTE" system is intended for non-contact measurement of blade mounting parameters in specified sections of GTE blade fence (blade wheel and distributors).

System also guarantees the optimum blade location in blade fence assembly.

Measuring principle is based on scanning of items blade with laser beam. Moving of laser head of optic-mechanical unit in relation to item being measured makes scanning. To measure blade-mounting parameters, corresponding blade scanning modes of item and calculation of its specified parameters are provided.

Set of profiles is measured as a result of blade mounting parameter scanning in specified section with various angles. Its gives full adequate information about real blade mounting parameters profile of GTE blade fence, including design parameters, which are stored in computer memory, transferred to Automated Control System of Technological Process and can be outputted to display or printer.

Automated measurements of blade mounting parameter geometry are carried out under specialised system software (SF) control. SF also calculates blade-mounting parameters, displays and registers real parameter values of blade mounting for every item type and size.

Measurements of blade mounting parameters are carried out non-contact and with high efficiency. Measuring results are displayed in visual form, registered and stored in computer memory. They can be outputted in the from of printed protocols in paper. Samples of measuring protocols are shown in the following figures.

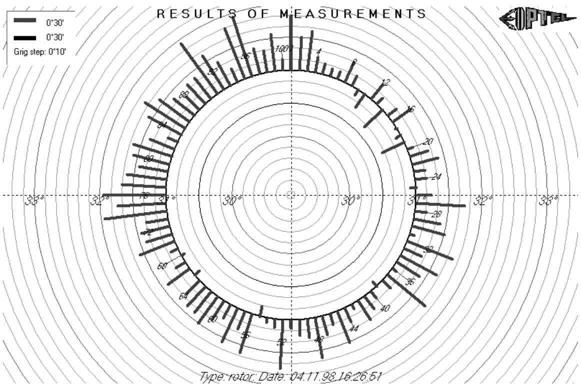

Fig. 11. Measuring results of blade mounting (turn) angles - circular chart

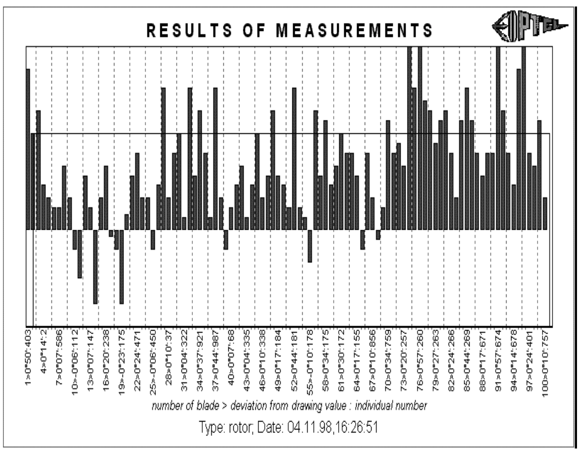

Fig. 12. Measuring results of blade mounting (turn) angles - line chart

4. EFFICIENCY OF INTRODUCING OF NEW LASER INSPECTION SYSTEMS

High accuracy and efficiency of non-contact measurements of "OPTEL" systems allows to automate labour intensive process of important item measurement, proved 100% objective inspection of hundreds and thousands of items types and sizes, with result logging in database. Objectiveness and speed of inspection allow to increase outcome of good product and product quality.

Inspection systems of new generation are high technological, had wide functional capabilities and long service life.

Necessity of CMM, templates and other outdated contact mechanical equipment application is annulled. Standard blades, templates and contra-templates and other auxiliary equipment, which is used in present, are not needed. It allows minimising operating cost and relieving toolmaker's shops.

"OPTEL" systems allow automating scientific research and experiments, related to shaping, including close tracking of materials and items.

Automation and carrying out of measurements in real time mode decreases cost of experimental research. Exception of subjective factors during measurement and processing of its result is very important.

Systems allow to carry out recalculation of base parameters optimum distribution of tolerance with regards to real geometry of every item workpiece.

Application of several systems exclude necessity of manufacturing and application of expensive outdated measuring equipment, used up to now (standard blades, templates and contra-templates), as well as relieves up to hundred operators. It gives considerable economy – up to several hundreds thousands and millions US$ per one GTE.

"OPTEL" systems are user-friendly and effective not only during the conversion of new items, but also during their lot production. At present there is no alternative for these systems.

It considerably increases accuracy of blade manufacturing, decreases labour intensity and reduces time of new item conversion with minimum operating cost. At present the 6th version of software is developed. Systems are compatible with CAD/CAM and computer-aided Automated Control System of Technological Process.

Computer-aided laser optoelectronic «OPTEL» has the main parameters on the world level with significantly less cost in comparison with known analogy.

If carry out comparative analysis of various visual means performance (such unit as template), it follows that new systems outperform the known systems according to practically all the parameters, including cost-performance ratio:
- in accuracy: by a factor of 10-20;
- in efficiency: by a factor of 10;
- in coat / efficiency ration: by a factor of 100-500.

In comparison with co-ordinate-measuring machine with comparable accuracy superiority of «OPTEL» system by efficiency is up to hundreds times, by cost/efficiency ration is thousands times. That is why "OPTEL" systems exceed outdated contact equipment by a factor of tens – hundreds thousands with regards to cost/efficiency ratio.

These systems are chatter stable, which allows to use them in shop conditions without air, water, etc. supply.

Introduction of new high efficient optoelectronic computer-aided inspection system allow to automate inspection fully, make it accurate, objective and fast, as well as upgrade blades and GTE gas-air track.

High efficiency of new laser systems is confirmed by long experience of successful application in aircraft engine plants during about ten years.

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