ENDOSCOPIC DIAGNOSTICS OF MARINE ENGINES

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Summary

There have been presented within the paper optic (qualitative) and digital (quantitative) methods of endoscoping internal spaces with industrial endoscopes and videoscopes presented within the paper which are applied willingly during a technical shape evaluation of the complex technical objects. They stand for a very effective diagnostic tool and they are very often reached by marine engines operators of both the fleets: naval and merchant. There have been also demonstrated selected metrological techniques that could be applied during diagnostic examination of the working spaces within marine diesel and gas turbine engines. An evolution of contemporary endoscopies as well as theoretical bases of optic and digital endoscopy has been brought forward. There have been also shown the methods enabling measurements of surface defects on the chosen inner parts of marine engines' construction structure. The are based on digital recording of endoscopy imagines: "Stereo Probe", "Shadow probe", laser method as well as RGB method.

Keywords: marine diesel and gas turbine engines, technical diagnostics, industrial endoscopy, measurements methods.

DIAGNOSTYKA ENDOSKOPOWA SILNIKÓW OKRĘTOWYCH

Streszczenie

W artykule przedstawiono optyczne (jakościowe) i cyfrowe (ilościowe) metody wziernikowania przestrzeni wewnętrznych z wykorzystaniem endoskopów i videoskopów przemysłowych, które stanowią bardzo efektywne narzędzie diagnostyczne, po które również coraz częściej sięgają eksploatatorzy silników okrętowych zarówno flot wojennych jak i wielu armatorów cywilnych jednostek pływających. Zaprezentowane zostały wybrane techniki metrologiczne, które mogą znaleźć zastosowanie w diagnostycznych badaniach przestrzeni roboczych okrętowych tłokowych i turbinowych silników spalinowych. Przybliżono ewolucję współczesnych endoskopów oraz podstawy teoretyczne endoskopii optycznej i cyfrowej. Zaprezentowano metody pomiaru defektów powierzchniowych wybranych elementów struktury konstrukcyjnej silników okrętowych, które bazują na cyfrowym zapisie obrazu endoskopowego: metodę „Stereo" („Stereo Probe"), metodę „Cienia" („Shadow Probe"), metodę laserową, metodę RGB.

Słowa kluczowe: okrętowe tłokowe i turbinowe silniki spalinowe, diagnostyka techniczna, endoskopia przemysłowa, metody pomiarowe.

1. INTRODUCTION

The visual investigation of surfaces creating internal spaces of the high - and medium-speed marine engines with use of specialist view-finders so called endoscopes is at present a basic method of technical diagnostics. The superficial structure of constructional material is visible during investigations like through magnifies glass, usually from sure increase, which makes possible the detection, recognition and the possible quantitative opinion of stepping out failures and the material defects, and in result - the opinion of degree of waste and the dirt of studied constructional elements.

In dependence on applied method of observation and the processing of visional painting of studied surface it distinguishes oneself the classic optical endoscopy, from utilization to this aim stiff (lenticular) borescopes and elastic (optical) fiberoscopes as well as the dynamically developing digital endoscopy, with use the more and more perfect videoscopes, equipped with miniature digital cameras at high resolution [6, 10].

2. MEASUREMENT METHODS APPLIED WITHIN DIGITAL ENDOSCOPY

During visual inspection through an optical endoscope of surface restricting internal spaces of engine it often lacks the reference patterns, which can be used for qualification of dimensions of detected defects. The observed dimension is the function of not only the real dimension of the defect, but also a distance between the speculum lens and studied surface. Because the manufacturers of engines pass the admissible values of superficial

defects of the most vulnerable constructional elements, the evaluation of real dimensions of defect represents the key diagnostic question. In traditional, optical approach to this question there is applied the comparative method, using with this aim the calibrated measuring profiles put on the ending of fiberoscope's speculum lens - [10]. Additionally, a suitable objective head should be chosen, which will assure, in direction of observation, the optimum angular limitation of field of sight straight on, alternatively - in direction of observation side. In dependence on a distance between the lens and studied surface there is matched such a width of sight field which will make possible maximum increasing the studied surface at being kept on the required depth of sharpness (the expressiveness of painting). Digital endoscopy brings in this regard completely new possibilities. The digital analyzers of painting, co-operating with measuring heads of "Stereo", "Shadow" or "Laser" type, basing on theory of triangulation[1], are able to qualify exactly a distance from the speculum lens to observed surface, and consequently to mark the dimensions of the detected surface defects. The measuring heads give the possibility of digital processing the stereoscopic effects, which enables measuring the seen paintings in such way, to give the quasi three - dimensionality impression - with its depth, the massiveness and the mutual distribution.

2.1. „Stereo" method

The basis of method "Stereo" is the suitable utilization of the prism proprieties splitting the painting, what makes possible for digital camera its registration from two points limited with span of parallactical lenses, similarly to human brain receiving information about the surrounding world from the pair of eyes placed each other in a distance of several centimeters (it is so called an eye optical base making about 65 mm) [3]. Paintings transmitted from parallactical lenses differ each other, and assignment of the high resolution, resultant, digital painting on monitor LCD represents the effect of realization of a computational algorithm. A distance from the lens to the observed surface is marked by counting pixels in horizontal plane of computer's monitor between analogous points of the left and right view of the observed element. The larger distance to the surface is observed the larger distance is between cursors of the left and right view on monitor screen. In the next stage of measurement technology the appropriate measuring technique should be chosen. The following metrological options are well-known for the realization of digital measurement within the "STEREO" method offered by significant manufacturers of endoscopy equipment i.e. OLYMPUS and EVEREST [7, 12, 14]:

- length,
- multisegment length, length broken (circuit),
- distance from point to base straight line
- depth (salience),
- area of surface (the area).

In every metrological option the measurement exactness is defined. When the operator possesses high skillfulness it reaches even 95-98% [12, 14].

2.2. „Shadow" method

Different area for the application of the triangulation theory, in order to mark the dimensions of surface defects takes the "Shadow" method being applied in digital endoscopy. The ending of videoscope's speculum head is equipped with the special optics generating the shadow about characteristic shape (the most often the line of straight line).inside the light stream (like the projector) on surface of the studied element. The projection of the shadow holds at known angle of the speculum head position, in relation to the observed surface and known angle of the observation sector. The shadow generated in the vicinity of detected defect is then located and recorded by camera CCD placed inside an assembly head. The nearer to the observed surface is the speculum head the nearer form the left side of monitor screen is the line of shadow. Because there is well-known the position of shadow generating the painting on the matrix of LCD monitor screen, a magnification of the painting can be simply enumerated. Moreover, the linear dimension of distance among individual pixels, and then the real dimensions of detected surface defects can be evaluated.

Within the "Shadow" method the same measurement options like in "Stereo" method are accessible.

The possibility of taking the immediate decision in case of doubts regarding proper interpretation (unambiguous distinction) of detected surface defects being effective with decrease or accumulation of material is the very essential advantage of the "Shadow" method. Such diagnostic problems step out during the evaluation process of technical state in the working space of combustion engines: piston or turbine.

Often, because of optical and light effects the usual dirt on surfaces of the air and exhaust passages, in figure of mineral settlings or the products of burning the fuel (the carbon deposit), is interpreted as the corrosive or erosive decrement of the constructional material. The depression of surface (its larger distance from the speculum head) is associated with the shadow line breaking and shifting towards the right side of the screen, and its salience (its larger approaching to speculum head) - the shadow line breaking and shifting towards the left side of the screen.

[1] W. Snellius was the creator of triangulation theory (1615). The measurement method consists in division of the measuring area into adjacent rectangular triangles and marks on the plane the co-ordinates of points by means of utilization of the trigonometrical functions.

The confirmed in investigations of diagnostic shipping engines utilitarian values characterize the method of "Shadow", and also high exactness which, at keeping on required conditions of the measurement, might achieve even 95% [14]. The maximum approach to studied surface of the speculum head represents the most essential factor of high measurement exactness (the line of shadow moves towards the left side as the speculum head gets closer to the surface) as well as maintaining perpendicular to this surface the position of speculum head (the line of shadow runs perpendicularly to the basis of a monitor screen).

2.3. Laser method

Laser method is the youngest measuring technology applied in digital endoscopy. In technical diagnostics two ways of laser rays utilization for the measuring surface defects are well-known. The first one is so called marker (multipoint) laser method, patented by German concern KARL STORZ Gmbh & Co. KG - [13]. The creature of the multipoint measurement is the estimation of distance from the videoscope's speculum head to studied surface (the increase of the real painting) on the basis of a base plane created by at least 3 the best well-fitting (from among 49) laser points of the marker matrix, throwed on the observed element by means of distracting optical arrangement of the measuring probe [10]. The smaller distance is to studied surface the larger is the shift of laser gauges towards left side of the monitor screen. The painting of surface, in the next stage of measurement realization, is recorded (stop-frame), and then by the utilization of triangulation theory of triangulation dimensions of detected defect are marked, in the following options (similarly to measuring systems of OLYMPUS and EVEREST company): the length, depth (the salience), the area, distance from the point to the base straight line.

A scanning method is the second way of application of laser rays to measure surface defects. The method has been patented by Australian company REMOTE VISION SOLUTIONS Pty Ltd [8]. The method is applied by the service groups of Boeing to search surface defects on a airplane hulk.

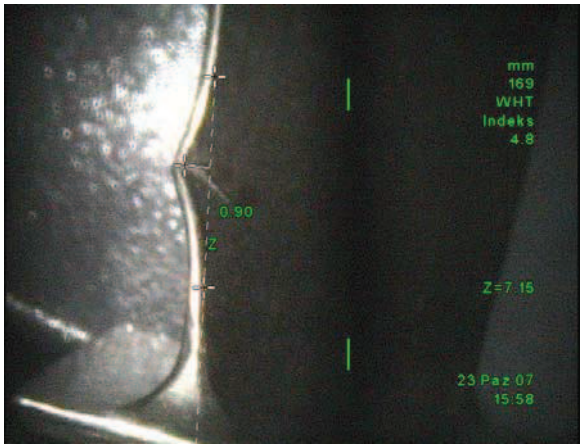
The optical arrangement of laser scanner makes the transformation (the dispersion) of the laser ray in the system of whirling mirrors. Dispersed laser bundle raining on studied surface undergoes reflection, which is directed on assembling lens and measuring detector. The quantity of reflected laser light is dependent on the state of studied surface. If the scanning laser ray shifts over the surface defect an absorption will occur, resulting from the smaller quantity of reflected light. As a consequence, the intensity of reflected light (density of light stream on assembling lens) is smaller than in the case surface being free from defects. The dimension evaluation of detected surface defects is then made on the basis of spectral analysis of distracted laser bundle in computer analyzing programme of the scanner. The usage of cylindrical optics in a laser bundle of the scanner enlarges superbly its application values (the laser ray is distracted into continuous circuit line) giving the possibility of technical state opinion about smaller surfaces e.g. internal spaces of combustion engines, especially intracylindrical spaces of piston engines.

2.4. RGB method

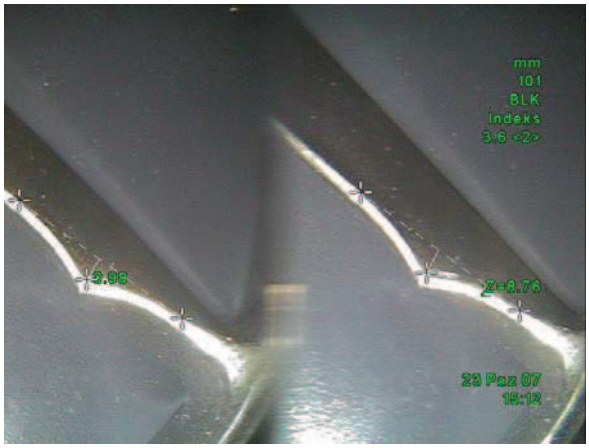
A digital painting recorded in videoscope's computer consists of separate elements, so called pixels. Each of them is specified as a group of value of colours: red, green and blue of the painting component in this point - RGB format. With them suitable confusion can get all different colours. Each of the colour in RGB format characterizes the tint, degree of clearness (or the brightness), the degree of saturation and the cleanness. It worth pointing out in this place that the colour, as a special feature of material objects, optically favoured, is dependent on the objects' physical-chemical structure, the way of absorbing and reflecting the light rays by the observed surface, the character of only light, properties of the air and peculiarity of surroundings (the light reflexes). Taking into consideration characteristic colours a simple spectral analysis of the colour composition reflecting the registered surface of construction element's painting can be carried out and this way its structure might be estimated. Because certain surface defects, as the alterations of physical properties of constructional material, characterize themselves with a definite pattern of colours spectrum it is possible to recognise closely was can for mediation of comparative analysis of ghostly paintings recognize early development stages of the unfavorable structure. The additional diagnostic information can be gathered by the analysis of digital record features on the borders of individual colours: their sharpness, brightness, surface density etc.

Within the range of conducted research works on diagnosing marine diesel engines worked out by the paper author's scientific team, there has been also undertaken trials to implement RGB method for the estimation of carbon deposits (degree of dirt) on the surfaces restricted the combustion chamber of cylindrical sets.

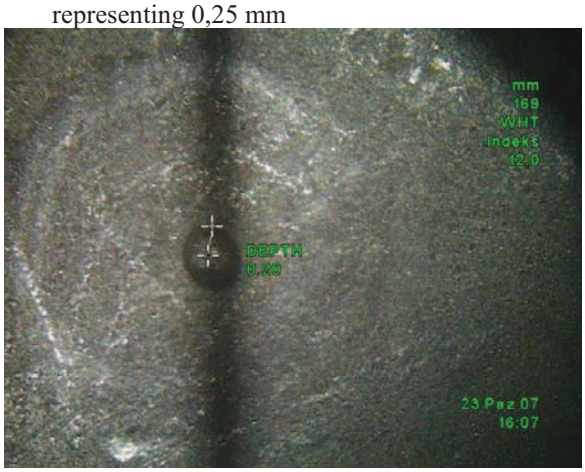
The registered results of routine endoscopic investigations of an engine being in current operation were used in this aim. IPEG format was applied in order to record the pictures. In spite of pilotage character (only) of undertaken investigations, during acquisition there has been paid special attention on keeping constant comparable intensity of lighting incidencing onto observed surfaces of the piston bottom, by making records in the same piston position in relation to Inner Dead Centre (IDC). Because of the character of making estimation (only intensity of the surface dirt) there has been given up full analysis of the colours distribution's intensity, but intensity of



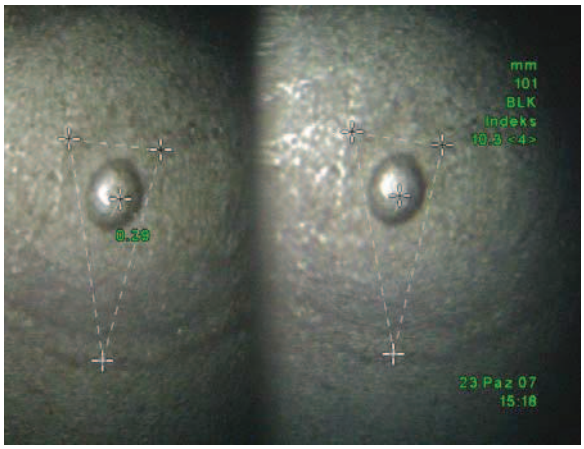
a) Depth measurement of dent on the blade's trailing edge by means of „Shadow" method in the option of "distance from point to base straight line" - 0,90 mm, at measurement accuracy index 4,8, representing 0,25 mm



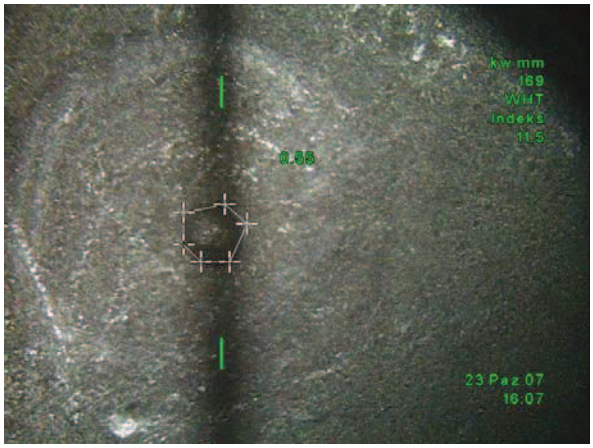
b) Depth measurement of dent on the blade's trailing edge by means of „Stereo" method in the option of distance from point to base straight line - 0,98 mm, at measurement accuracy index 3,6, representing 0,5 mm



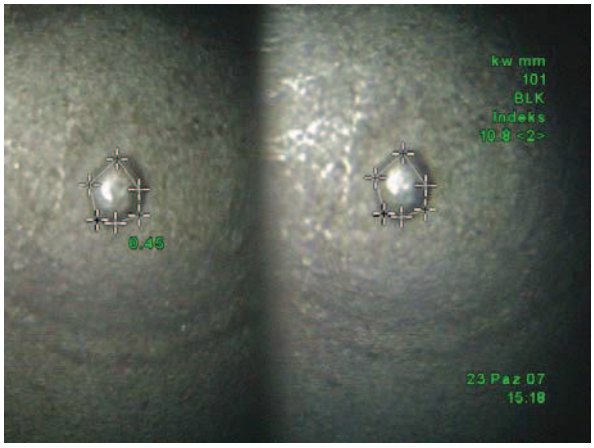
c) Convexity measurement of surface „bulge" on the blade-bed by means of „Shadow" method - 0,20 mm, at measurement accuracy index 12,0, representing 0,15 mm



d) Convexity measurement of surface „bulge" on the blade-bed by means of „Stereo" method - 0,29 mm, at measurement accuracy index 10,3, representing 0,1 mm



e) Surface „bulge" area measurement (closed broken line) on the blade-bed by means of „Shadow" method - 0,55 mm^2, at measurement accuracy index 11,5, representing 0,1 mm^2



f) Surface „bulge" area measurement (closed broken line) on the blade-bed by means of „Stereo" method - 0,45 mm^2, at measurement accuracy index 10,8, representing 0,1 mm^2

Fig. 1. The results of measurement of surface defects on blades of naval gas turbine engines with the utilization of "Stereo" and "Shadow" method

greyness tints schedule of monochromatic paintings has been taken into consideration. The introduced method which bases on usable Able of Image the Analyser v3.6 programme analysing the paintings in relation to intensity of pixels occurrence of given colour or the pixels of greyness tints was described in publication in detail [10].

The registered results of performed by the author endoscopic investigations of the naval gas turbine engine's rotor blades are presented in fig. 1. It order to estimate dimensions of detected surface defects "Stereo" and "Shadow" method have been applied as well as "EVEREST" videoscope XL PROTM type has been put into use (thanks to politeness of company representatives in Poland).

3. CONCLUSION

The detecting the material defects in the internal spaces of machines and industrial devices by means of endoscopes utilization represents one of the youngest methods of technical diagnostics, in contrary to medical diagnostics, where it has been acknowledged as the key method of searching pathological states inside human body since ancient times.

Introduced in the article optical (qualitative) and digital (quantitative) method of examining visually internal spaces with the utilization of optical endoscopes and industrial videoscopes are more and more willingly applied method in the evaluation process of technical state of the complex technical objects. They constitute the very effective diagnostic tool and the operators of marine engines (diesel and gas turbine) apply them very willingly in both the fleets: war and merchant. Especially merchant shipowners are very interested in endoscopy application during engines servicing.

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