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INFLUENCE OF RADIATION DIFFRACTION UPON METROLOGICAL PARAMETERS OF THE IR LINE SCANNER

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Abstract – The influence of IR radiation diffraction upon geometrical resolution of the IR line scanner has been analysed in the paper. Analysis of IR line scanner properties in band 3 – 5 µm and 8 – 12 µm proved that when applying the aperture diaphragms the influence of the radiant diffraction upon geometrical resolution may be significant. This influence is stronger for larger f- numbers N in the applied optical systems. It was shown that for large values of f-numbers the thermal resolution of the IR line scanner can be improved by reducing the bandwidth of the electronic system of the scanner, without considerable deterioration of geometrical resolution.

Keywords IR line scanner, metrological parameters

1. INTRODUCTION

The correctness of thermal transformations obtained by means of IR line scanner equipments is a function of several factors which are dependent on the equipment construction. The dependence on construction factors that are of significant influence upon the quality of thermal transformations, are parameters of transformation synthesis system. These construction factors/parameters of elements used in the IR scanner measuring line determine values of the metrological parameters of the equipment. The most important of them are: thermal resolution (TR) ΔT and geometrical resolution (GR) ΔG [1], [3]. Construction parameters of the imaging analysis system that influence the TR are different for different measuring conditions (e.g. filters and diaphragms change parameters of the optical line).

The influence of radiation diffraction upon the IR line scaner GR and (what is connected with TR) upon the frequency matching of the image analysis system to representation synthesis system for diaphragms with large f-numbers N, has been analysed in the paper.

2. GEOMETRICAL AND THERMAL RESOLUTION OF THE IR LINE SCANER

2.1. Geometrical resolution

The geometrical resolution ΔG is defined as the scanner ability to reproduce the geometrical details in the thermal image. There are many ways in literature to define this parameter. For our aims, it seems, that the best way to describe the geometrical details is the description of this abilities by the modulation transfer function (MTF). The MTF function is the dependence on spatial frequency. So the geometrical resolution ΔG is such a value of spatial frequency f_{pxg} defined in the image plane where the modulation transfer function of the IR scanner it equals 0.5

$$\Delta G = f_{xg}$$
$$MTF_n(f_{xg}) = 0.5 \qquad (1)$$

2.2. Thermal resolution

Thermal resolution is defined as the capability to distinguish between two temperatures which are very close each to other. There are several methods, known in literature, to define this parameter. In this paper ΔT is defined as the noise equivalent temperature difference (NETD) [1], [2], [3].

3. FACTORS DETERMINING THE MODULATION TRANSFER FUNCTION

The independent units of the IR scanner measuring line are: optical system (described by MTF_{no}), detector (described by MTF_{nd}), and electronic system (described by MTF_{ne}). The MTF_n function of the scanner may be described as the product of the particular MTF function of the optical and electronic systems and the MTF function of the detector:

$$MTF_n = MTF_{no} MTF_{nd} MTF_{ne} \qquad (2)$$

The filtration of the optical system (described by MTF_{no}) is caused by infrared radiation diffraction and by aberrations of the optical system (if it is not sufficiently corrected). The detector filtering abilities (described by MTF_{nd}) are connected with geometrical dimension of the effective surface and with inertia of this element. The electronic unit filtration is connected with definite band width of the signals transmission and with the indicator finite ability to reproduce the geometrical details. Indicator filtration is not significant and it well not be future considered.

4. MODULATION TRANSFER FUNCTION OF THE OPTICAL SYSTEM

Assuming that the optical system of the scanner is corrected and it has the entrance pupil in shape of a circle and that it co-operates with the detector of selective spatial characteristic, it is possible to obtain the MTF_{no} defined by the following equations:

$$MTF_{no}(f_{px}) = \frac{\left|\int_{-\infty}^{+\infty} e_{wni}(x)\exp(-j2\pi x f_{px} dx\right|}{\left|\int_{-\infty}^{+\infty} e_{wni}(x)dx\right|} \quad (3)$$

where:

$$e_{wni} = \frac{\int_{-\infty}^{+\infty} e_{wn}(x,y)dy}{\int_{-\infty}^{+\infty} e_{wn}(0,y)dy} \quad (4)$$

but:

$$e_{wn}(x,y) = \frac{\int_{-\infty}^{+\infty}\left[\frac{2J_1\sqrt{x^2+y^2/\lambda N}}{\pi\sqrt{x^2+y^2/\lambda N}}\right]\tau_\lambda m_\lambda D_\lambda^* \frac{d\lambda}{\lambda}}{\int_{-\infty}^{+\infty}\tau_\lambda m_\lambda D_\lambda^* \frac{d\lambda}{\lambda}} \quad (5)$$

where: λ – wavelength; m_λ – emittance, D^*_λ – spectrum detectivity of detector, J_1– Bessel's function of the first grade, $e_{wn}(x,y)$ – standard weighted radiation intensity in the point of x, y coordinates (image plane).

Equation (5) describes the distribution of standard weighted radiation intensity in the diffraction spot that is created by the corrected optical system as an image of the point existing in the subject plane. Equations (3), (4) and (5) will be used to determine the influence of filtering abilities of the optical system upon the MTF_n.

5. MODULATION TRANSFER FUNCTION OF THE DETECTOER

It has been assumed that: effective surface of the infrared detector used in scanner is in regular square; one pair of sides of the effective detector is parallel to the direction of line analysis; detector is the inertial element of the first grade (only with one time constant). Based on above assumptions the MTF_{nd} may be defined as:

$$MTF_{nd}(f_{px}) = \frac{\sin(\pi a f_x)}{\pi a f_x}\frac{1}{\sqrt{1+(2\pi f_{px} v \tau_d)^2}} \quad (6)$$

where: a – side of the square effective surface of the detector, v – speed at which the image of an object is moved over the detector surface, τ_d time constant of the detector. Usually $a \geq 0{,}1$ mm, $\tau_d \leq 0{,}5$ μs and $v \leq 30$ m/s so in equation (6) the factor describing the inertia of the detector can be omitted. Equation (6) will be used to determine how the filtering abilities of the detector influence the MTF_n of the scanner.

6. MODULATION TRANSFER FUNCTION OF THE ELECTRONIC LINE

It has been assumed that the band width transmission of the IR scanner electronics is limited by the low – pass filter with an attenuation of 20 dB/dec. Based on this assumption MTF_{ne} may be determined by:

$$MTF_{ne}(f_{px}) = \frac{1}{\sqrt{1+\left(\frac{f_{px}}{f_{pxgr}}\right)^2}} \quad (7)$$

where: f_{pxgr} – boundary spatial frequency of the filter ($f_{pxgr}= f_{gr}/v$; f_{gr} – boundary frequency of the filter). Equation (7) will be used to determine how the characteristic of electronic filter influences the MTF_n.

7. INFLUENCE OF DIFFRACTION UPON MTF_n

Applying equations (2)-(7) it has been stated that that when diaphragms are not used, the main factor influencing on MTF_n is the spatial filtration of the detector. The larger the f–number in used diaphragms, the stronger is influence of the optical filtration upon MTF_n. The diffraction of the radiation can spoil the IR scanner geometrical resolution by about 31% in 3-5 μm band (SW) and 60% in 8-12 μm band (LW) - it has been assumed that the transmission band of the electronic system has been chosen in such way that there is no influence upon the MTF_n. Practically electronic systems are not realised in such way that they have no influence on MTF_n. A too broad transmission band of the electronic unit can spoil ΔT without any significant influence on ΔG. Based on literature [1] date it is possible to state that the f_{pxgr} value is determined as:

$$f_{pxgr} = \frac{1}{2a} \quad (8)$$

The dependence (8) describing the role of matching the image analysis system with the representation synthesis system connect the value of f_{pxgr} with the dimensions of detector effective surface. It seems that general rule concerning the way of determining f_{pxgr} value should connect this value with the modulation transfer function describing spatial filtration of the optical system and the detector. So equation (8) has been replaced by another one where the boundary frequency of the electronic filter is equal to such a spatial line frequency that equation (12) is fulfilled.

$$MTF_{nd}(f_{pxgr})MTF_{no}(f_{pxgr}) = 2/\pi \qquad (9)$$

When $MTF_{nd}MTF_{no} = MTF_{nd}$ the values of f_{pxgr} are equal for equations (8) and (9). The result of limitation f_{pxgr} according to (9) for N=20,4 are fallowing: for 3-5 μm band thermal resolution improved by 23 % and geometrical resolution worse by 11 %; for 8-12 μm band thermal resolution improved by 38 % and geometrical resolution worse by 19 %. The above results are valid only if MTF_{no} is connected only for IR scanning equipped with aberration less optical systems. Practically, it is impossible to make optical systems that are aberration less. Spatial filtration of the real optical systems is connected both with radiation diffraction and with aberration. It depends on the precision with which the optical system has been corrected, manufactured and adjusted, which of factors will be dominating. Generally, it is possible to state that aberrations of the optical system becomes smaller with the increase of the f–numbers N. Physically it can be explained that the strongest aberrations are introduced into the system by boundary zones. It can be stated that application of the aperture diaphragms in optical system with aberrations reduce the aberration spot radius and thereby improve the geometrical resolution of the system. However, in case of well corrected optical systems, the inverse phenomena may occur and impairing of GR is observed because of reaction increase of radiation diffraction (wave nature of radiation makes the increase of diffraction spot diameter with the increase of the f- numbers N). As the result the following conclusions can be stated in dependence of diffractional or aberrational factor: GR of IR line scanner improves (for strong aberrations of the optical system); GR of IR line scanner improves (for strong aberrations of the optical system); GR of IR line scanner dose not change when the influences of both factors are balanced.

4. CONCLUSIONS

Radiation diffraction can significantly influence the GR of the IR line scanner with series structure of measuring line. This influence is stronger for smaller dimensions of the effective surface and for larger values of diaphragm f-numbers used during measurements.

In the IR line scanners which are equipped with a sufficiently corrected optical system and with infrared detectors with effective diameters of about 0,1 mm, it is possible, when applying the aperture diaphragms with great f- numbers N , to reduce the transmission band of the IR line scanner electronic system in a way which improves the TR and insignificantly impairs the GR at the same time.

REFERENCES

[1] R. D. Hudson, *Infrared System Engineering*, Wiley Interscience, New York, 1969.

[2] X. P. V. Maldague, *Theory and Practice of Infrared Technology for Nondestructive Testing.* John Wiley & Sons, Inc., New York, 2001

[3] W. Minkina, *Pomiary termowizyjne – przyrządy i metody*, Wydawnictwo Politechniki Częstochowskiej, Częstochowa , 2004