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Research on measurement of thickness and damage degree of coatings based on lock-in thermography

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Abstract. Coatings is widely used and plays an important role in modern equipment, but it is lack of effective and rapid detection methods. From coatings thickness measurement principle of lock-in thermography, this article proposed unique coatings equal thickness processing method and damage monitoring method. The experimental results show that the method can quickly and efficiently characterize the coating thickness uniformity and the damage degree.

1. Introduction

Special functional coatings such as thermal barrier, corrosion prevention and radar wave absorption in modern weapon equipment are widely used, plays a key role in improving weapon survival ability, penetration ability and operational performance. In the process of coatings using, it is inevitable that some of the coatings wear, fracture, fall off, and so on. The rapid and effective detection and evaluation of the coating thickness and damage degree are of great significance to ensure the performance of equipment.

How to solve the problem of nondestructive testing of coating thickness and defect effectively. Since 90s last century, this has been a hot of research and exploration of foreign scholars [1-4]. In China, many researchers, for example Huo Yan, Li Yanhong, Guo Xingwang, Wang Zhiyong et al, studied and explored the pulse method of coating defects, but little progress. Infrared phase lock-in technology (LT, Lock-in Thermography) was first proposed by Professor G.Busse of University of Stuttgart in 1992. After years of development, has made great progress in recent years. During 2010~2012 years, Liu Junyan from Harbin Institute of Technology carried out detection research on infrared lock-in method for composite materials and composite coatings [5]. The result shows that lock-in thermography can achieve reliable detection of deep defects and multilayer defects of composite materials and coatings. In the year of 2015-2016, Zhang Jinyu and others have made a significant progress in the study of coating thickness measurement by lock-in method [6-7].

However, the monitoring of key quality indicators such as the uniformity of coatings and the damage degree are still lack of in-depth study. This paper will carry out a research on this issue and propose a set of effective monitoring methods.

2. Principle of lock-in thermography

The basic principle of lock-in method is to determine the thickness of coatings by detecting the phase difference between the thermal excitation signal and the measured surface temperature signal. The heat wave intensity of emitted excitation source is changed according to the sine law, so the temperature of coating surface is the same frequency sinusoidal signal. When the thickness of coatings is different, the heat wave transmission distance is different, the temperature phases of coatings

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surface with different thickness are different, so the coatings thickness can be expressed as a function of phase. According to the study of literature 7, the new formula of coatings thickness measurement should satisfy an equation as follow.

$$L = a\bullet\varphi^3 + b\bullet\varphi^2 + c\bullet\varphi + d \quad (1)$$

Where L is the thickness; φ is phase angle; a, b, c and d are constants to be determined. They can be calibrated by four point calibration method[6-7] according to the thermal characteristics of the measured coatings. The relationship between the phase and the thickness and the thermal diffusion length μ is shown in figure 1.

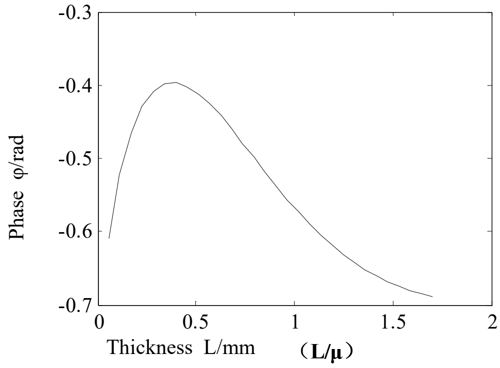


Figure 1. Relationship between phase and thickness and thermal diffusion length μ

In the process of using coatings, erosion and wear damage generally are little, the thickness of coatings is also in the original value after wearing off, so when testing the uniformity of coatings, only to test a small range of thickness. The uniformity of coatings can be detected only by using the relationship of the monotone stage. The theory is that when the thickness of coatings is near the thermal diffusion length (0.8μ~1.2μ), the phase value of the surface temperature signal of coatings is approximately linear with the thickness of the coatings. By using the relation, it is easy to reflect the difference of the thickness by the difference between the phases, so as to judge the uniformity.

3. Experimental materials and methods

The radar-wave absorbing coatings is taken the most simple and effective way for the realization of modern weaponry stealth performance, is widely used in the modern weapon system. Radar-wave absorbing coatings thickness restricts the stealth performance of weapon equipment. Because the microwave absorbing coatings is generally thin and belongs to ferromagnetic coatings, the conventional ultrasonic and eddy current methods have poor detection effect. According to the wave absorbing materials used in weapon systems, we respectively make uneven thickness of the radar-wave absorbing coatings specimens at two kinds of substrate, using infrared thermal lock-in detection technology to test coatings uniformity.

(a) Aluminum substrate (b) Steel substrate

Figure 2. Two different matrix specimen

The aluminum and steel are selected for the base material, and the aluminum plate and the steel plate with a size of 200mm * 100mm * 4mm are manufactured respectively, and the thickness of the aluminum plate and steel plate are required to be uniform and the surface is smooth and smooth, and the structure is shown in figure 2.

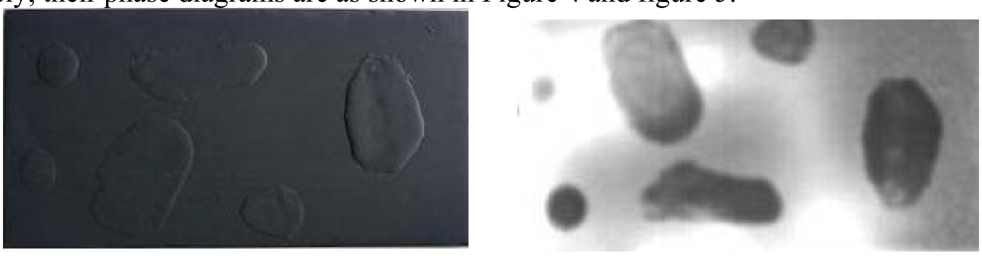
Carbonyl iron powder was used as absorbent and epoxy resin adhesive was used to prepare the absorbing coatings. The particle size of iron powder is 2.5-3.5μm. Epoxy resin use SL3215 fully transparent stone edge A, B glue. The carbonyl iron powder, SL3215A glue and SL3215B glue are arranged uniformly by the proportion of the volume ratio of 1:1:1, and the wave absorbing coatings is made. The absorbing coatings with different thickness between 0.5mm and 1.5mm were respectively coated on the aluminum substrate and steel substrate, and the coatings specimens were shown in figure 3.

(a) Aluminum substrate coatings (b) Steel substrate coatings

Figure 3. coatings specimens with different thickness

4. Uneven thickness detection and visual display

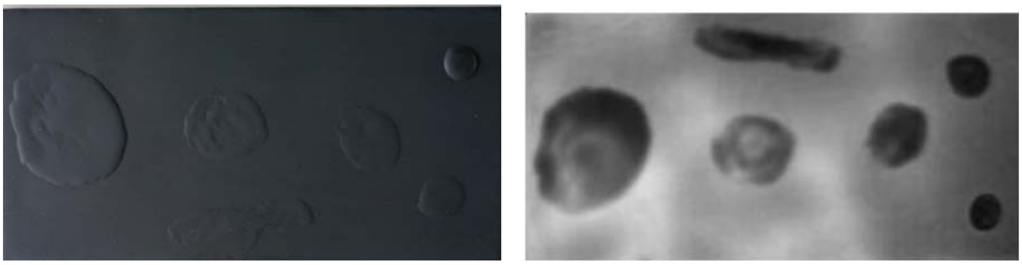
In the previous section, two specimens with different thickness were prepared. The surface of coatings was uneven, and the thickness of coatings was about 1mm. The thermal diffusion coefficient of the coatings is measured to be $2.10 * 10^{-7}$. When the thermal diffusion length is equal to 1mm, the thermal excitation frequency f can be solved, which is the needed frequency of the thickness uniformity of coatings. By calculation, the loading frequency of selected thermal excitation source is 0.0625Hz. Under the detection conditions, modulation frequency is 0.0625Hz, sampling frequency is 25Hz, sampling 2 cycles, the two pieces of uneven thickness of coatings specimens were detected, respectively, their phase diagrams are as shown in Figure 4 and figure 5.



(a) specimen photo (b) phase diagram

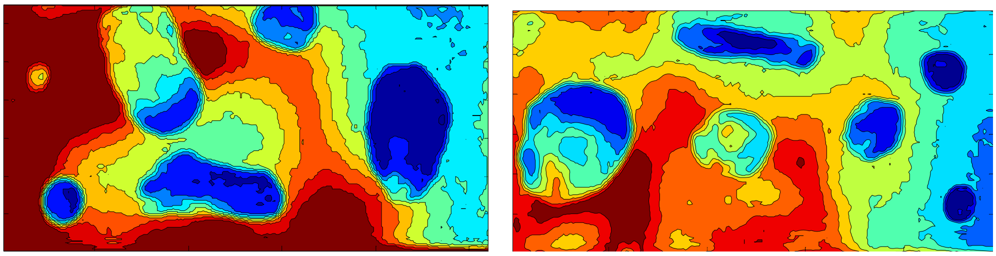
Figure 4. phase diagram of uneven thickness of steel substrate

Obviously the phase diagram can judge out bulges on the surface of coatings, and the corresponding relationship with the physical map was compared, but the uniform representation of grayscale phase of the coatings surface lack for visual, so it need further processing. According to the isohypse line thought of military map, we draw the equal gray amplitude lines in the two phase diagram (i.e. equal phase lines or equal thickness lines), the same thickness area of coatings surface are connected by lines, and give them the same color, their same thickness color map were obtained. The processing results are shown in Figure 6. The visualization of coatings uniformity can be show, the coatings thickness in different positions are very intuitive.



(a) specimen photo (b) phase diagram

Figure 5. phase diagram of uneven thickness of aluminum substrate



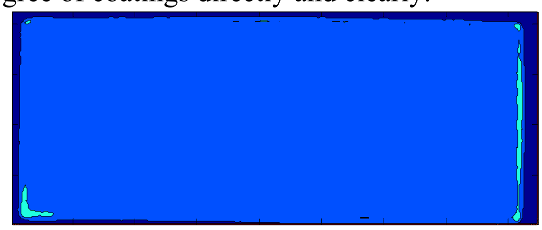
(a) Equal thickness image for steel substrate coatings (b) Equal thickness image for aluminum substrate coatings

Figure 6. visualization of uneven coatings

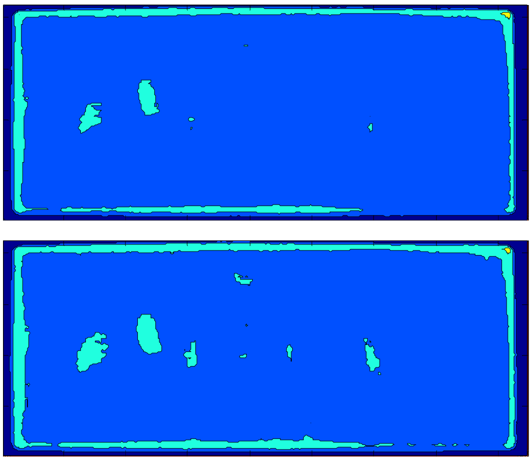
5. Monitoring and evaluation of coatings damage

Through the visualization analysis of coatings phase diagram, although the uneven coatings can be very intuitively showed, but we can't determine whether the coatings specimen can still meet its requirements only according to this an image. The past and present equal phase diagrams of the coatings should be compared, so as to realize the evaluation of the coating damage degree. According to the idea, a new monitoring and evaluation method is proposed to measures and monitor the degree of damage of coatings.

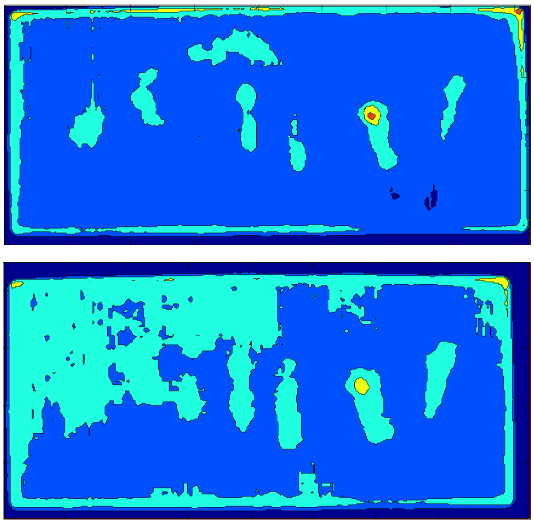
Firstly, the thickness uniformity testing of surface coatings of new operation equipment are carried out, and get the visual equal thickness image which the uniformity meet itself requirements. During the use of equipment, regular thickness uniformity testing was detected. The visual thickness images are recorded. We may compare the changes of thickness of visual image, and get its final thickness visual image until the equipment coatings probably no longer meet the requirements. By means of the statistical analysis of these images, we can find out the unevenness rule of coatings in different periods. When getting a coatings thickness and its visual image, we can estimate the period in which the coatings wear, so as to judge whether the coating still meet the requirements, and realize the evaluation of damage degree of coatings. Figure 7 shows the results of a simulated coatings wear test, which can show the wear degree of coatings directly and clearly.



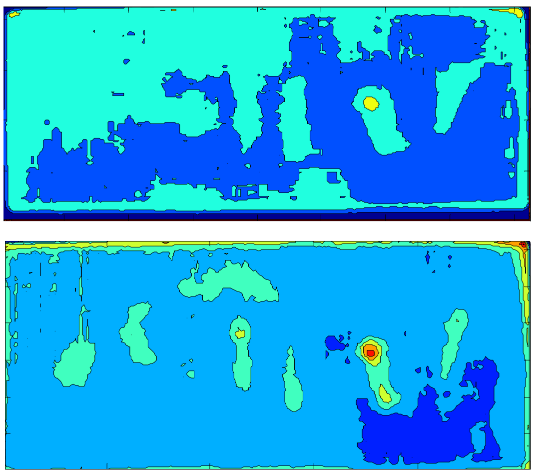
(a) Not wear



(b) Slight wear



(c) Moderate wear



(d) Severe wear

Figure 7. wear degree of coatings

6. Conclusion

The infrared lock-in method was used to detect the thickness of coatings, and the obtained phase diagram was visualized to get the image of the equal thickness. The image can intuitively show coatings uniformity. A new method for monitoring the degree of coating damage is proposed based on the continuous measurement of the thickness of the coatings. The experimental results show that the method based on the phase lock-in thermography can be used to characterize the thickness uniformity and the damage degree of the coatings.

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References

[1] Barbara Franke. Non-Destructive Evaluation of Thermal Barrier Coatings with Thermal Wave Imaging And Photostimulated Luminescence Spectroscopy [D]. M.S. University of Central Florida Orlando, Florida, 2005.
[2] Lanhua Wei, Antonia Pajares, Brian R. Lawn. Effect Of Mechanical Damage On Thermal Conduction Of Plasma-Sprayed Coatings [J]. Journal Of Materials Research, 2009, 11(6): 1329-1332.
[3] Peter D. Engblom, Susan C. Mantell. Non-Contact Thickness Sensor for Thermal Barrier Coatings using Thermal Wave Interferometry, National Science Foundation (DMII 9457156), US.
[4] Tsui Y C, Doyle C, Clyne T W. Plasma sprayed hydroxyapatite coatings on titanium substrates Part 1: Mechanical properties and residual stress levels[J]. Biomaterials, 1998, 19(22): 2015-2029.
[5] Liu Jun yan, Dai Jing min, Wang Yang. Theory and experiment of IR lock-in thermography with sequence processing [J]. Infrared and Laser Engineering, 2009,38(2):346-351.
[6] Jin-Yu Zhang, Xiang-bin Meng, Dong-dong Wang, Numerical simulation and analysis of lock-in thermography for thickness measurement of coating [J]. Infrared and Laser Engineering, 2015, 44(01)6-11.
[7] Jin-Yu Zhang, Xiang-bin Meng, Yong-chao Ma, A new measurement method of coatings thickness based on lock-in thermography, Infrared Physics & Technology, 76(2016)655-660.