Nondestructive Evaluation of BSCC Artificial Heart Valves

Milan Sapieta[1[0000-0003-1356-1168]], *Vladimír* Dekýš[1[0000-0001-5683-2058]], *Pete*r Weis[1[0000-0002-1669-4890]], and *Martin* Svoboda[2[0000-0002-7344-1531]]

[1]Faculty of Mechanical Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina
[2]Faculty of Production Technology and Management of Jan Evangelista Purkyně University in Ústínad Labem, Na Okraji 1001, Czech Republic

Abstract. The subject of investigation is a set of four artificial heart valves made of electrically conductive material, namely the alloy Ti-6Al-4V. Notches of defined geometry with gradually increasing depth were formed on these BSCC (Bjork-Shiley Convexo-Concave) valves. These defects are created on the so-called output strut, which serves as a support mechanism for the controlled movement of the so-called occluder disc and they have been investigated. The method which was used is ultrasonic infrared thermography, where the object was excited by the UTVIS EDEVIS ultrasonic system and the response was detected by the FLIR SC 7200 infrared camera. The postulate for the use of this method is that the excitation signal may be periodically pulsate or in any other way modulated by certain amplitude frequencies, called "lock-in frequency". Lock-in thermography is a type of active lock-in method. The results of damage detection on these relatively complicated objects are compared and discussed.

1 Introduction

Non-destructive testing of materials (NDT) plays an important role in the quality management system of the production process. It enables the early detection of internal defects in the product or semi-finished product, which could prevent its effective use or cause a structural accident after a certain period of operation. We use a number of methods using different physical principles to detect and quantify the detected errors in the field of non-destructive testing.
The advantage of non-destructive methods over destructive methods is that the product remains unchanged after further testing for further use. NDT test methods for individual types of semi-finished products and products are prescribed in the relevant standards and regulations. From this point of view, the decisive factor is usually the customer's request, which determines according to which standard or regulation the product is to be assessed for NDT.

2 LOCK-IN thermography

The essential for the utilize of this technics is that the excite signal could be periodically throbbed or in some other method modulated by particular amplitude frequencies, called "lock-in frequency" $\mathrm{f_{lock-in}}$. Lock-in thermography is a kind of active lock-in technique. This means that to excite specimenby heat, this heat must be generated periodically and correlation usage the lock-in method is applied to every heat subscription of each individual pixel on the view of the registered device.
Digital lock-in form correlation comprise of averaging the consequence of the recorded values $\mathrm{F_k}$ and method of weighting factors $\mathrm{K_k}$ to the overall amount of recorded values M [1]:

$$S = \frac{1}{M}\sum_{k=1}^{M} F_k\, K_k \qquad (1)$$

There for *S* is the output signal.
When the excitation signal is harmonic then the most convenient correlation function is also harmonic (sine, cosine) function. This type of lock-in correlation is named sin/cos or narrowband correlation. It could be obtained either by narrowing the bandwidth of the recorded signal or utilized the amount of harmonic functions for $\mathrm{K_k}$ in the formula (1) [1].
The principal benefit of the sin/cos correlation is that it makes possible to user to take into account the phase of the signal after the evaluation (off-line) when it is used two-channel correlation. Two-channel correlation intends that there were applied two kinds of weighting factors, one approximates a sin-function and the second approximates cos-function. Correlation is transferred twice in parallel with both kinds of weighting factors [1-5]:

$$K^0(t) = 2\,sin(2\pi f_{lock-in} t) \qquad (2)$$
$$K^{\pi/2}(t) = 2\cos(2\pi f_{lock-in} t) \qquad (3).$$

Next the first channel measures the component in-phase with the sin-function, and the other channel measures the component in-phase with the cos-function, which is π/2 phase-shifted to the sin-function [13].
If formulas (2,3) are inputted into formula (1) than the outcome of the two correlations over a complete number periods is [5-10]:

$$S^0 = \frac{1}{n}\sum_{i=1}^{n} F_i\, K_i^0 \qquad (4)$$
$$S^{\frac{\pi}{2}} = \frac{1}{n}\sum_{i=1}^{n} F_i\, K_i^{\frac{\pi}{2}} \qquad (5)$$

Where $\mathrm{S^0}$ is named the in-phase signal and $\mathrm{S^{\frac{\pi}{2}}}$ is usually named the amplitude signal. Both signals could be either positive or negative [14-18].

2.1 UTVIS EDEVIS

Ultrasound lock-in thermography is a strong measure method for detect indication of cracks, disbonds, or delaminations. UTVIS is based on digital high-power ultrasound generators and converters as excitation sources and high-sensitive infrared camera.
Ultrasound thermography (or Vibrothermography) uses the interaction of mechanical and thermal waves to detect material defects. If the defect in the component absorbs the injected high-energy ultrasound waves, it is heated locally (selective defective dark field method). The resulting temperature gradient on the sample surface is measured with an infrared camera, which visualizes the scattered energy. Depending on the application, there are two derivatives of this method: the very fast analysis by the decay phase and the sensitive

Lockin method. In both cases, the evaluation calculates the time delay between the injected energy and the thermal response, leading to a robust and reliable technique that is constant against surface properties or ultrasonic distribution [19].

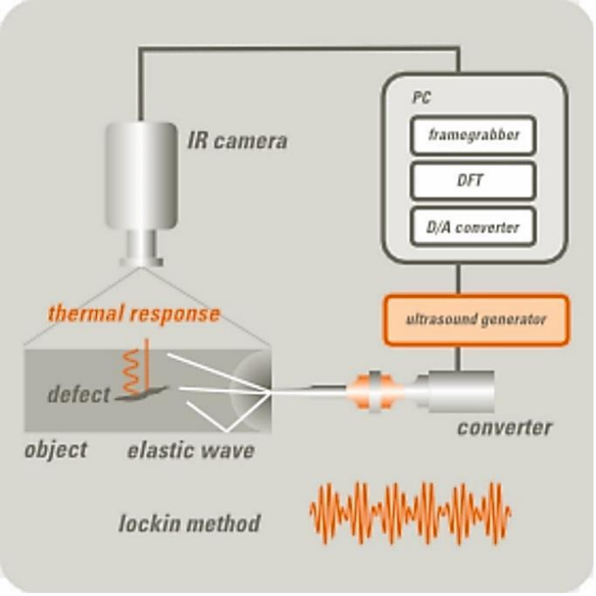

Fig. 1. Schematic representation of the lock-in principle with ultrasonic excitation Utvis [19].

3 Measurement

As the samples werechosen4 artificial heart valves made of electrically conductive material, namely the alloy Ti-6Al-4V. Three of samples were damaged by cutting they were created with gradually increasing depth. The sample was placed under ultrasound exciter and is subsoiled by a holder suitable shape (Fig. 2).

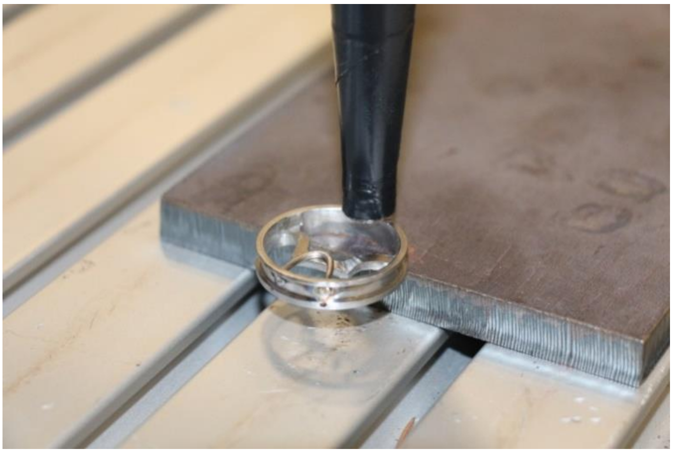

Fig. 2. The sample under ultrasound exciter.

Than the sample was excited by choice modulated frequency while the defect was displayed. The entire operationof excitation wasrecorded by infrared camera (Fig. 3). Setup of infrared camera was the same for every single excitation of frequency. The 50 Hz of frame rate was selected on infrared camera. The emissivity value was chosen1 in the software environment because this quantity does not affectof the measurement result.

Fig. 3. Infrared camera recording process of sample excitation.

The program, that was used to evaluate every single image, is called the DisplayImg and it was supplied with the excitation equipment. This program uses the theoretical foundations of the lock-in technique, as it is explained in the first section of this article.
Since a first form of excitation was chosen sweep excitation. This is type of excitation which get along through whole area of modulated frequencies. It is supposed to notice the whole process of excitation and then select the most suitable modulated frequency at which are detected damages on the measured subject.
After detect the suitable modulated excitation frequency, resolution of radiation energy was succeeded drawn in the program like in phase and amplitude display[10-14].Furthermore, only the displays in phase were evaluated. In the first sample can be damage observed by the light area, with excitation frequency 0.03 Hz (Fig. 4). On the second sample it is possible to see damage when excitation frequency is 0.006 Hz (Fig. 5). The third sample was excited by frequency 0.065 Hz when damage was displayed (Fig. 6).

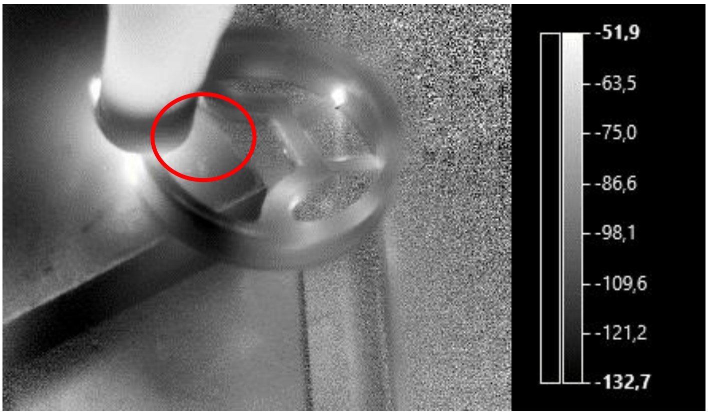

Fig. 4. The first specimen after excitation, the frequency of excitation is 0.03 Hz.

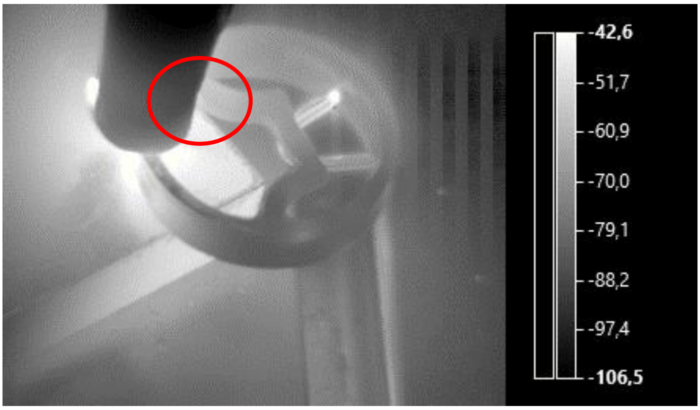

Fig. 5. The second specimen after excitation, the frequency of excitation is 0.006 Hz.

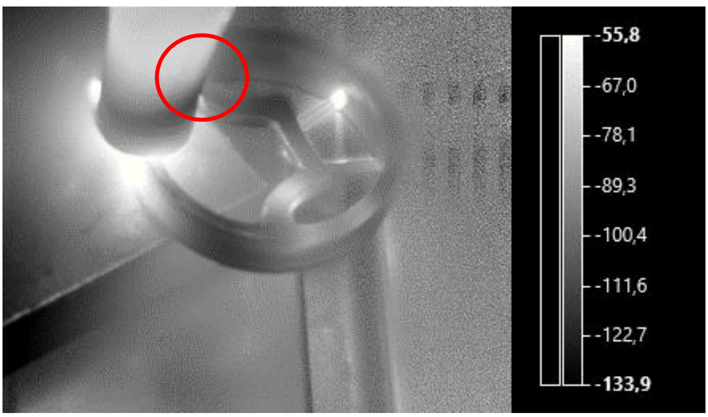

Fig. 6. The third specimen after excitation, the frequency of excitation is 0.065Hz.

4 Conclusion

Non-destructive testing of material was carried out for the purpose of this measurement. As the samples were selected four artificial heart valves made of electrically conductive material, namely the alloy Ti-6Al-4V. Damages of defined geometry were created on valves. These damages have increasing depth. Device with an ultrasonic excitation UTv is which work by the lock-in method for NDT was used as excitation device that test the samples. At first it was executed ultrasonic excitation through the total area of modulated frequency, by this excitation was selected modulated frequency that was able find defects on the samples.

For important facts can be regarded the knowledge that, as of oscillation (if modification of the excitation area frequency, then when the exciting frequency correspond, with its own than is a displayed resonances) and in this sort of excitation (ultrasound) is a reaction in the IR field dependents on instant variables of the excitation signal.

Defect was created by the light fields by variation the radiation structure on interpreted pictures. The method has proper to be anappropriate to solution for NDT testing to find defectson heart valves.

Acknowledgement

This paper was supported by VEGA grant No.1/0141/20 and the VEGA grant No. 1/0510/20.

References

1. M. Sapieta, P. Sulka, M. Svoboda Localization of delamination in composite test specimen. XXII Slovak-Polish Scientific Conference On Machine Modelling And Simulations 2017 (MMS 2017) Book Series: MATEC Web of Conferences, 157, Article Number: 01015 (2018).
2. T. Dodok, N. Cuboňová, I. Kuric Workshop programming as a part of technological preparation of production. Advanced in Science and Technology Research Journal 11, 1, 111-116 (2017).
3. P. Krawiec, G. Domek, Ł. Warguła, K. Waluś, J. Adamiec The application of the optical system ATOS II for rapid prototyping methods of non-classical models of cogbelt pulleys. MATEC Web of Conferences, 157, 01010 (2018).
4. P. Krawiec, A. Marlewski Profile design of noncircular belt pulleys. Journal of Theoretical and Applied Mechanics, 54, 2 561–570 (2016).
5. A. Sapietová, M. Sága, I. Kuric, et al. Application of optimization algorithms for robot systems designing. International Journal of Advanced Robotic Systems 15, 1 (2018).
6. M. Sága, P. Kopas, M. Uhričik Modeling and experimental analysis of the aluminium alloy fatigue damage in the case of bending - torsion loading. Procedia Engineering 48, 599-606 (2012).
7. P. Kopas, M. Blatnický, M. Sága M. Vaško Identification of mechanical properties of weld joints of AlMgSi07.F25 aluminium alloy. Metalurgija 56 (1-2), 99-102 (2017).
8. M. Saga, M. Vasko, Z. Sagova, M. Handrik Effective algorithm for structural optimization subjected to fatigue damage and random excitation. Scientific journal of Silesian University of Technology – Series Transport 99, 149-161 (2018).

9. M. Vaško, M. Blatnický, P. Kopas, M. Sága Research of weld joint fatigue life of the AlMgSi07.F25 aluminium alloy under bending-torsion cyclic loading. Metalurgija 56, 1-2, 94-98 (2017).
10. L. Jakubovičová, M. Sága, M. Vaško Numerical study of influence of mutual slewig of roller bearing rings on the principal stresses at contact area. Scientific journal of Silesian University of Technology – Series Transport 84, 83-91 (2014).
11. V. Dekýš, A. Sapietová, O. Števka Understanding of the dynamical properties of machines based on the interpretation of spectral measurements and FRF.Conference: 51st International Scientific Conference on Experimental Stress analysis (EAN 2013) Location: Litomerice, Czech Republic Date: Jun 11-13 (2013).
12. A. Sapietová, R. Petrech, M. Petrovič Analysis of the dynamical effects on housing of the axial piston hydromotor. Novel Trends In Production Devices And Systems Book Series: Applied Mechanics and Materials, 474, 357-362 (2014).
13. M. Kekez, L. Radziszewski, A. Sapietova Fuel type recognition by classifiers developed with computational intelligence methods using combustion pressure data and the crankshaft angle at which heat release reaches its maximum. 20th International Conference Machine Modeling And Simulations, MMS 2015 Book Series: Procedia Engineering, 136 (2015).
14. O. Stalmach, V. Dekys, P. Novak, M. Sapieta Processing of results from a thermal fem analysis using the lock-in method and comparison with experiment. Scientific journal of silesian university of technology-series transport. 104, 159-168 (2019).
15. V. Dekýš, Z. Stankovičová, P. Novák, O. Stalmach The contribution to the modal analysis using an infrared camera. : MATEC Web of Conferences, 157, 05003 (2018).,
16. V. Dekys, O. Stalmach, J. Soukup, A. Sapietova, L. Rychlikova Detection of composite damage by IR NDT using ultrasonic and optic excitation. XXIII Polish-Slovak Scientific Conference On Machine Modelling And Simulations (MMS 2018) Book Series: MATEC Web of Conferences, 254, 05004 (2018).
17. M. Sapieta, V. Dekys, P. Pastorek Using of activ thermography and lock-in method with ultrasound exication for detection of material defects. Scientific Reports, 7, 1386 (2014).
18. M. Jurkovic, T. Kalina, L. Jancosek, R. Kadnar, P. Gorzelanczyk, K. Jerabek Proposal of Conversion the Tugboat Engines to Diesel - LNG Operation. Advances In Science And Technology-Research Journal, 13, 4, 129-142 (2019).
19. EDEVIS Homepage https://www.edevis.com/content/en/ultrasound_thermography.php.