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THE RATE OF DECOHESION OF A GAS TURBINE BLADE AS ASSESSED WITH THE X-RAY COMPUTED TOMOGRAPHY (CT)

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Abstract

The overheating of the material is among major reasons for failures/damages to gas turbine blades throughout the entire process of operating aircraft turbine engines. The essential method of diagnosing condition of the blades is metallographic examination being however a destructive technique. The paper has been intended to discuss one of non-destructive testing (NDT) methods, i.e. the X-ray computed tomography (CT), and capabilities of applying it to diagnose changes in condition of gas turbine blades. 'Tomography' is a comprehensive term to define a set of diagnostic techniques to produce three-dimensional images that present cross-sections through detail items under scrutiny. The CT is a transmission diagnostic technique that allows layered models (images) of details to be acquired. Most commonly, it is used in research laboratories and throughout the process of the product quality inspection.

The paper delivers findings of the preliminary investigation into the assessment of health/maintenance status of gas turbine blades by means of the X-ray computed tomography. The results gained have been successfully verified using the metallographic examination techniques. It has been found that the radiographic imaging method enables recognition of types, sizes, and locations of internal faults in the blades while generating three-dimensional images thereof.

Presented are capabilities of the high-resolution X-ray inspection machine with computed tomography (CT), V/tome/x, furnished with a 300 kV tube, and the CT data processing capabilities of the VG Studio Max software solution, high-performance CT reconstruction included (using an optional module). At the same time work is under way with the X-ray tube for nanotomography with the 0.5 μm resolution to examine, in particular, modern composite materials.

Keywords: *gas turbine, blade, maintenance status, diagnosing, X-Ray computer tomography (CT), composite materials*

1. Introduction

The process of aircraft operation involves defects and failures of various types that affect aircraft driving systems, in particular rotating parts, where turbine and compressor blades are the most endangered components. Such defects entail the need to dismount the entire engine and, consequently, to set the aircraft for a long downtime and to bear substantial financial expenses.

Defects of blade may be classified to several groups according to underlying reasons that are mutually interdependent. The most frequent reasons for defects and failures include:

- manufacturing faults,
- unskilled repairs and upgrades,
- improper operation and maintenance.

Shortcomings in quality of manufacturing and repairs comprise a large group of operational defects that are detected in inner areas of avionic engines, e.g. during endoscopic inspections. These defects are not in the scope of the user's control and users in no way may counteract them. Such defects may be manifested during the entire lifetime period of the equipment and demonstrate random and stochastic nature.

Repairs and overhauls of driving systems provide the opportunity to evaluate technical condition of rotating parts in a more detailed manner with the use of various NDT techniques that include:

- visual inspection,
- dye penetrant inspection (DPI) or liquid penetrant inspection (LPI),
- ultrasonic inspection,
- conventional (2D) X-ray inspection,
- other techniques.

However, diagnostic capacities of all the foregoing techniques are strictly limited, so they are still insufficiently reliable for assessment of internal invisible defects or failures like subsurface cracks or similar. Currently technical condition of blades (e.g. overheating) is assessed by diagnostic personnel chiefly by visual inspection with the possibility to verify the diagnostic conclusions by means of destructive methods when metallographic examinations are carried out.

Under such circumstances, the method of computer tomography (CT) enables to achieve much better results as compared to other test techniques. Although it is a non-destructive technique, it allows detection and verification of defects and flaws also inside the material solid.

Currently a broad program of research and development studies is in progress with the aim to assess applicability of the CT method to microstructure investigations of a wide spectrum of metallic alloys, polymeric and composite materials as well as materials for electronic on-board systems that are incorporated into avionic designs.

As it is generally known, the Computed Tomography (CT) is a kind of X-ray tomography but it enables acquisition of 3D images from investigations when objects under tests are multiply X-rayed from various directions. The device for Computer Tomography is referred to as a tomograph, usually a Computer-Assisted Tomograph (CAT) and the acquired images - tomograms. The principle for development of 3D images is explained in Fig. 1.

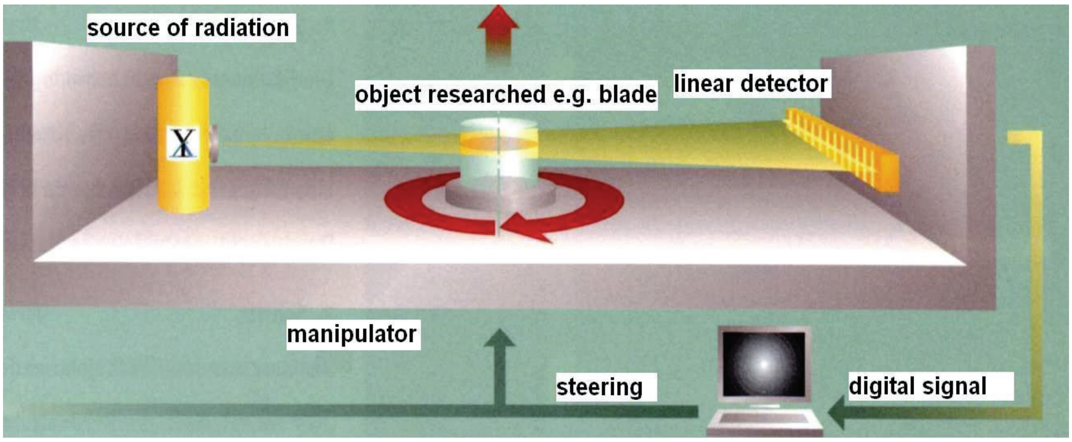

Fig. 1. The example of a tomography investigation with use of a linear detector [6]

The CT method is widely used for industrial applications as a non-destructive method suitable for quality control of manufacturing processes and finished products. Implementation of that method to verification of components embedded into avionic structures requires a broad range of tests that must first confirm that the obtained results are correct, reliable and coincide with the outcome from other methods.

Diagnostic of condition demonstrated by turbine rotor blades requires high imaging accuracy for internal structures of components e.g. in order to check dimensions of inner walls, detect a flaw or a defect. The most advanced X-ray tubes that are currently in use enable really accurate tomographic examinations and resolution of images obtained after processing of X-ray data is as high as 0.5 µm. It is really good accuracy that enables detection of the most frequent flaws and defects with dimensions magnitude of tenth fractions of millimetres. Execution of test cycle for a single component needs some time interval and depends on the component size (i.e. its dimensions), the material grade the component is made of, investigation task, accuracy of data processing for imaging results and other requirements related to the examination.

In 2012, the Air Force Institute of Technology (ITWL) was awarded the grant from the Ministry of Science and Higher Education for purchase of research equipment. Owing to the grant, ITWL was able to purchase a tomograph (Computer-Assisted Tomograph - CAT) from ITA-Polska, the representative of GE Phoenix. The device type is v/tome/x m 300 (Fig. 2) and its tube is operated with the maximum power of 500W at 300 kV voltage. It has also a tube for nanotomography with the power of 15W at 180 kV. Purchase of that cutting edge equipment made it possible to launch research studies on a wide spectrum of materials that are used in avionic industry, such as various steel grade, alloys of non-ferrous materials (including titanium), polymers, elastomers, fiber and aggregate composites, ceramic and electronic materials, etc. Non-destructive tests (NDT) can be carried out with unsurpassed resolution. The tomograph is capable of detecting defects with the size below 0.5µm with use of the lamp for the 180 kV voltage or flaws in materials with high density, e.g. titanium blades of avionic turbojet engines when the lamp for the 300kV voltage is employed. The maximum weight for parts to be examined is up to 50 kg. The time intervals necessary to examine engine components, e.g. turbine blades, range from 20 to 30 minutes.

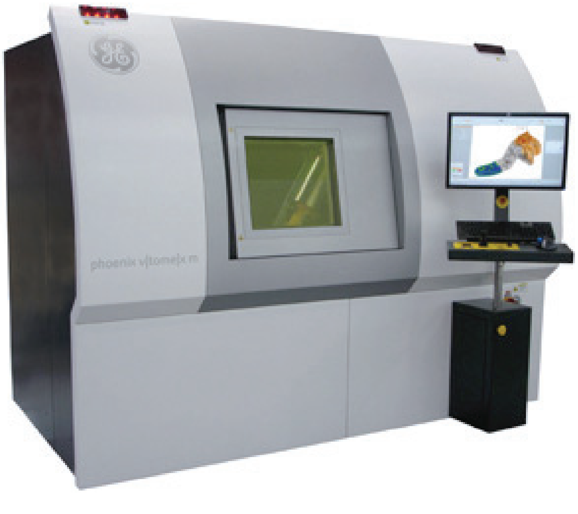

Fig. 2. The V/Tome/x m 300 tomograph purchased from GE

2. Experimental investigations

2.1. The method of visual assessment based on processing of images for blade surface acquired at daylight

The method of visual inspection if chiefly employed for non-destructive testing of technical objects. When any optical tools or instruments are used, in particular a videoscope, inspection of areas inside the objects is possible without the need to disassemble the inspected device. Acquisition and processing of information that can be useful for diagnosis of machinery parts can be sequenced in the following way:

- illumination of the object under investigation with white light on the appropriate background,
- acquisition of images from the object under investigation,
- digital analysis of images,
- presentation of information about the images.

The illuminated surface of turbine blades can be examined by a light-sensitive detector (a CCD matrix along with an optical system – an optoelectronic system) owing to the source of secondary light reflected by the blade surface. The CCD matrix counts the number of photons that reach the matrix area, i.e. it can measure the energy of light beams that arrive to each individual pixel. In case of computer-based visual systems, the images are acquired from the environment by means of an optoelectronic device – a videoendoscope (Fig. 3). Such an approach enables indirect diagnosing of the object under investigation through processing and analysis of data acquired in the form of digital images.

Fig 3. The optoelectronic device – the videoendoscope [3]

Use of really advanced diagnostic tools based on computer-aided technologies makes it possible to improve reliability of assessment and evaluation when the condition of turbine blades is inspected. Such technical equipment enables to gradually get rid of the adverse effects entailed by so called 'human factor' and its influence on examination results. Consequently, it will improve safety of flights and contribute to reduction of expenses on operation of turbojet avionic engines. When the experiential diagnostic realm is left exclusively to subjective assessment of a human operator, it may lead to many expensive errors due to the decision that the operator takes and that are always burdened by some degree of uncertainty. Fig. 4 presents examples of defects recorded for blades installed on the rotor of the HP turbine within a turbojet engine. The method of visual inspection makes it possible to detect and evaluate only surface defects, such as overheating, flaking of blade surface, corrosion, surface erosion or presence of surface cracks. Unfortunately, the method is insufficient to find out how deep the crack is as well as to evaluate deformation of blade walls in case of blades cooled from the inside.

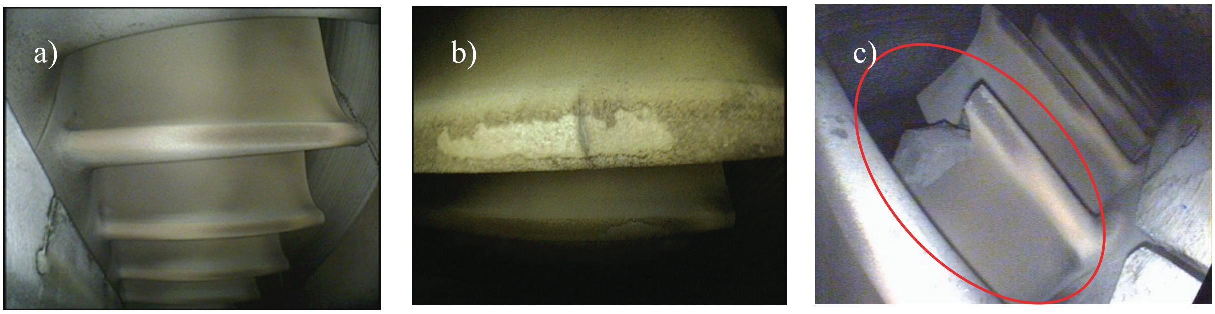

Fig. 4. Examples of defects affecting rotor blades of a gas turbine: a) overheating of the material on the edge of attack; b) flaking of the blade surface and a crack on the edge of attack on the blade leaf; c) tear out of a blade leaf

2.2. X-ray based Computer Tomography (CT)

The method of Computer Tomography (CT) makes it possible to assess how deep the cracks of gas turbine blades extend inside the blade bodies or how much the blade material suffers from decohesion. After having the blade X-rayed the acquired 2D images are superposed to produce 3D views. The analysis of images provides information about technical condition of blades. The software offers the possibility to make cross-section of the objects along three planes. Such sections enable accurate identification and location of defects and failures as well as taking geometrical measurements down all the planes. Therefore, it is possible to determine depth of cracks, directions of their propagation and, consequently, predict applicability of blades for further operation.

Figure 5 and 6 present a turbine blade where a crack is detected on its edge of attack and explain how to measure the crack size.

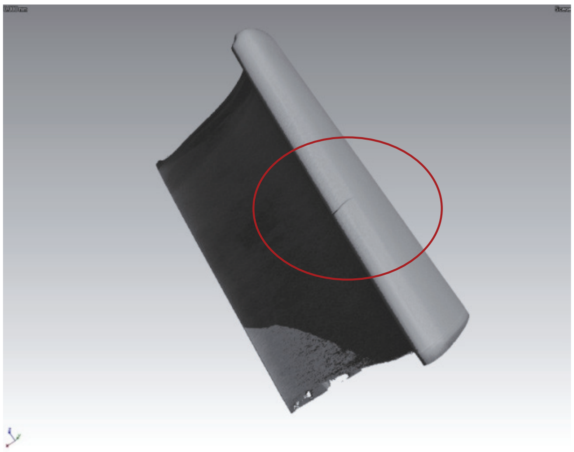

Fig. 5. Crack on the edge of attack

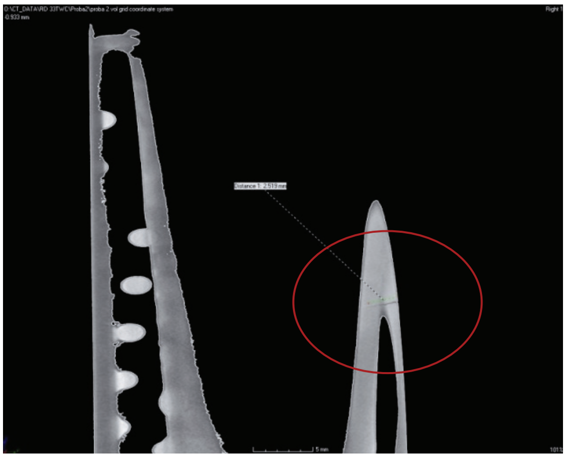

Fig. 6. Dimensioned crack on the edge of attack

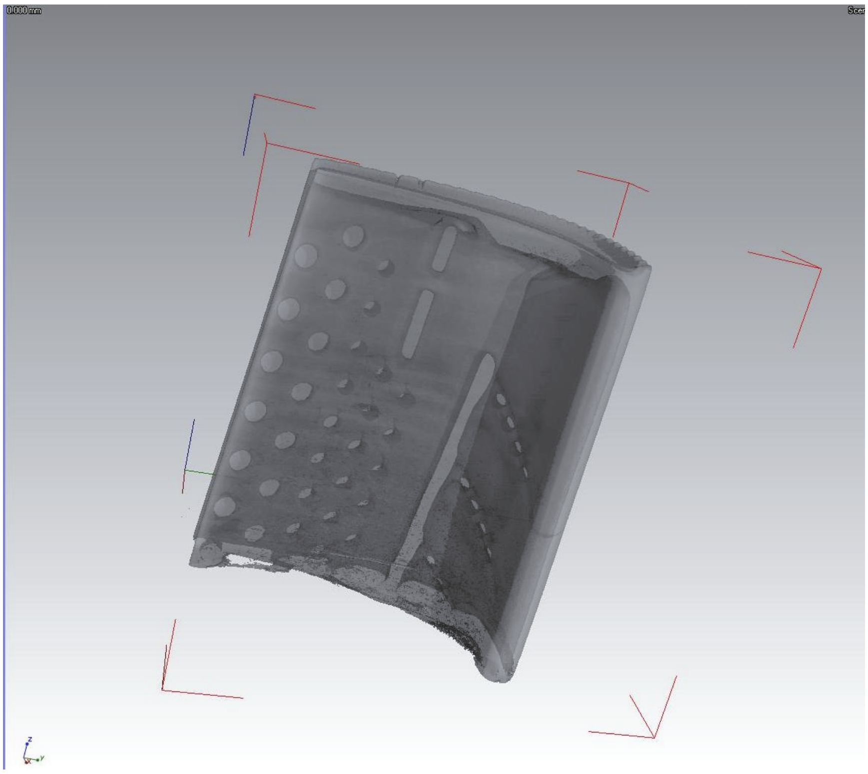

Fig. 7. The example of the space inside the turbine blade

Currently the efficiency of cooling ducts for turbine blades and lack of obstruction is checked during repairs by measurements of water flow intensity where water passes through the inner space of a blade over a specific time. It is a time-consuming method that provides quite poor accuracy. Application of the Computer Tomography method makes it possible to achieve 3D image of turbine blades in a very short time and the images can be analysed in any cross-section and up to any depth. It provides a very realistic image of inner ducts designed for cooling of blades (Fig. 8, 9). Reliability and trustworthiness of such verification is extremely important since in case of any errors any inaccuracies may lead to thermal failures of blades during turbine operation.

The software for analysis of images acquired as a result of tomographic examination offers the functionality to inspect the parts under tests to the desired depth. The advanced tools for processing examination results are able to 'remove' slices of material to the depth as required by the operator. It is the method that provides high accuracy in determination of the surface roughness, both on the outer and inner sides of turbine blades (Fig. 8, 9).

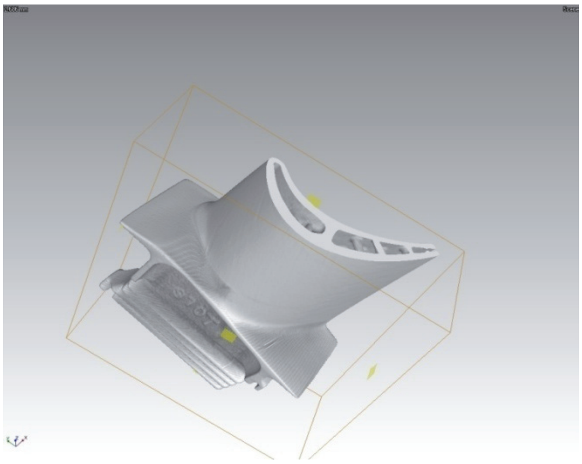

Fig. 8. The blade cross-section with the view of the inner space

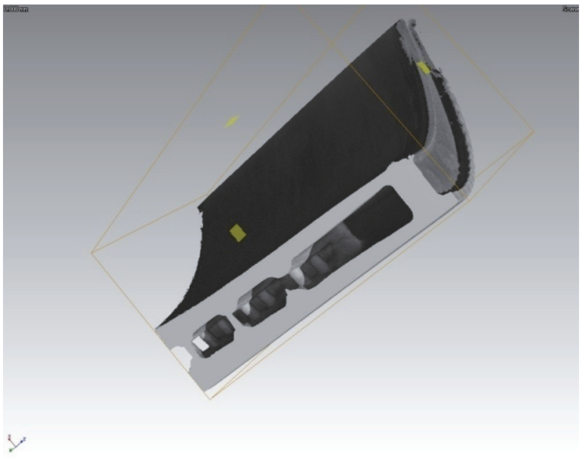

Fig. 9. The blade cross-section with the view of the inner space

The next application area of computer tomography is the possibility to evaluate thickness of protective coatings applied onto blades of both the turbine and the compressor (Fig. 10). The obtained results enable drawing of the conclusion that it is feasible to find out how much the protective coatings are deteriorated due to flaking or erosion. Such examinations have already been possible exclusively with the use of destructive testing by means of metallographic microsections.

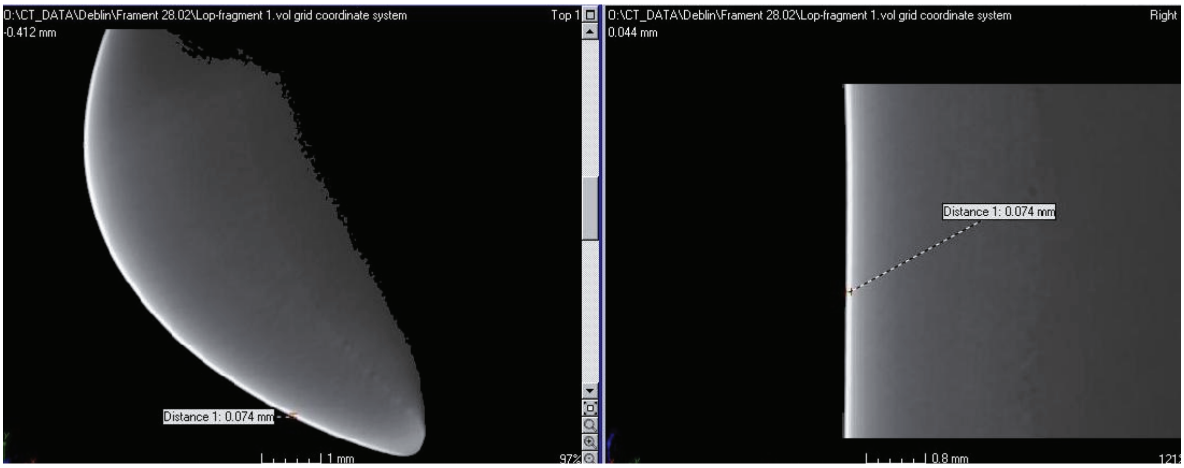

Fig. 10. View of protective coatings applied onto a leaf of a turbine blade and examples for measurements of the coating thickness

Computer tomography enables monitoring of actual wall thickness, also in case of inner or invisible ones. It is extremely important for verification of machine parts, e.g. castings. Upon reconstruction of the real part the operator can measure the casting dimensions and carry out automatic analysis of the wall thickness. It is the tool that automatically indicates deviations from the assumed dimensions specified in engineering drawings. The distribution of the thickness parameter can be presented in the graphic manner with the use of the scale of colours. It enables immediate verification whether the blade is manufactured correctly or not (Fig. 11).

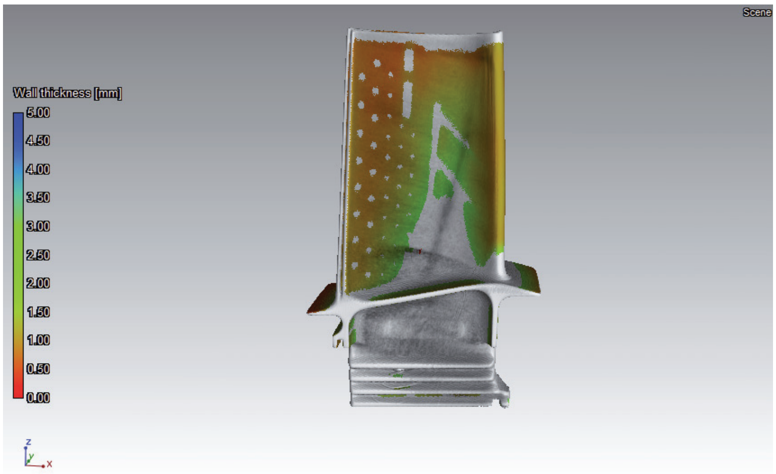

Fig. 11. The example of the image for the thickness of coating applied onto a leaf of a gas turbine blade acquired by means of a tomograph [7]

4. Conclusions

The process dedicated to verification of technical condition demonstrated by blades of gas turbines incorporated into turbojet engines is a very important operation that must be carried out with extreme care during the phases of manufacturing, repairs and operation of engines. The basic method of visual inspection, aided by optical or optoelectronic instruments makes it possible to evaluate the technical condition of blades on the basis of their colour, roughness of geometrical parameters of the blade leaf. When gas turbines are operated according to the method of so-called tolerated failures, e.g. cracks, it is impossible to evaluate the crack depth. It is very important, in particular in case of blades that are cooled from the inside, since throughout fracture of blades substantially decreases the strength of the blade and reduces its lifetime.

The method of Computer Tomography (CT) enables determination of the crack size and its depth in a more reliable and quick manner as well as it enables to assess decohesion of the blade material. Application of the CT method combined with other non-destructive test method substantially improves the probability that the defect or damage of the turbine blade shall be detected in the early stage.

The method can be also successfully applied to other components of the avionic structures as well as completely assembled devices. It is very important when it is necessary to establish whether all details are correctly deployed within machinery subassemblies, e.g. power packs of the control systems, safety devices or electronic components.

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