doi.org/10.15407/tpwj2017.11.02

RESTORATION REPAIR OF ELEMENTS AND UNITS OF GAS TURBINE ENGINES

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Restoration of gas turbine engines is very urgent and at the same time difficult task, the solution of which provides significant cost savings. The work reflects the results of developing an efficient and reliable method for repairing gas turbine engine blades using electron beam welding. The technology of repair of three types of blade airfoil defects using welded-in pieces was mastered. It is shown that electron beam welding is ideal for solution of the problem of replacement individual elements of permanently assembled units of gas turbine engines. 4 Ref., 14 Figures.

Keywords: *electron beam welding, gas turbine engines, restoration repair, replacement of units, technological methods, spot and extended defects, welded-in pieces*

Appropriateness of restoration repair of expensive parts of the gas turbine engines (GTE) does not raise doubts [1].

For example, the main reason of early replacement of the aircraft GTE in their operation is damage of titanium blades of the fan and compressor as a result of foreign objects coming in the engine. Usually engine operation is allowed at insignificant defects of leading and trailing edges of the blade airfoil without tears. Part of similar (i.e. without tears), but somewhat larger defects can be repaired directly on the engine. Thus, for example, material rising near the nicks is dressed and bends of the blades are eliminated by flattening. Then, the repaired places are polished. Sometimes, removal of the nicks due to smooth rounding of the edge of up to 10–12 mm radius is allowed. In contrast, correction of local damages of the blades, exceeding allowable norms, requires dismantling of the damaged blade and repair under production conditions. Usually such a repair lies in mechanical removal of the defective zone till the boundaries of knowingly undamaged blade metal with further connection (welding, brazing) of a welded-in piece of corresponding size instead of it and with technological tolerance on thickness for acquiring a necessary profile of blade repair section using further mechanical treatment [2–4].

Generally, the solution on repair permissibility for each specific defect of the blade is made by the certified repair organization, following the next aspects, i.e. belonging of the blade to low pressure compressor (LPC) or high pressure compressor (HPC), blade type (namely, blade or vane), number of compressor stage, whether it is leading or trailing edge of the airfoil, and at last, evaluating directly the defects sizes, their quantity and location relatively to the places of maximum service stresses (including resonance ones).

Our task lied only in development of an efficient and reliable method, which fundamentally will allow such a repair using electron beam welding (EBW) under domestic production conditions. The technological methods were mastered on the spot and extended de-

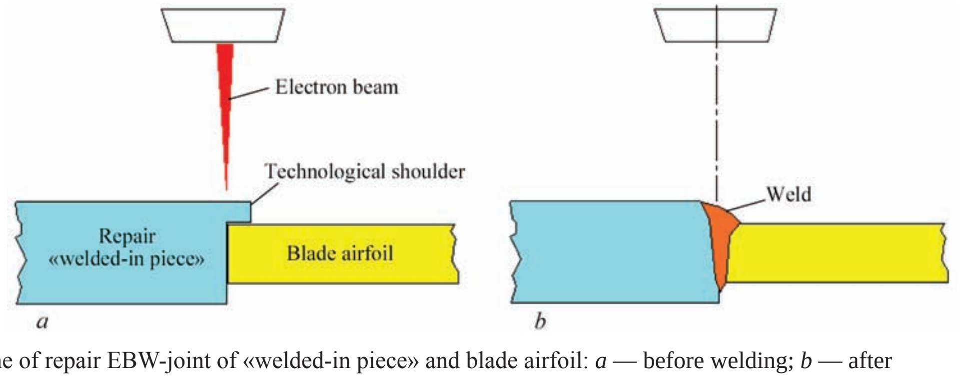

Figure 1. Scheme of repair EBW-joint of «welded-in piece» and blade airfoil: *a* — before welding; *b* — after

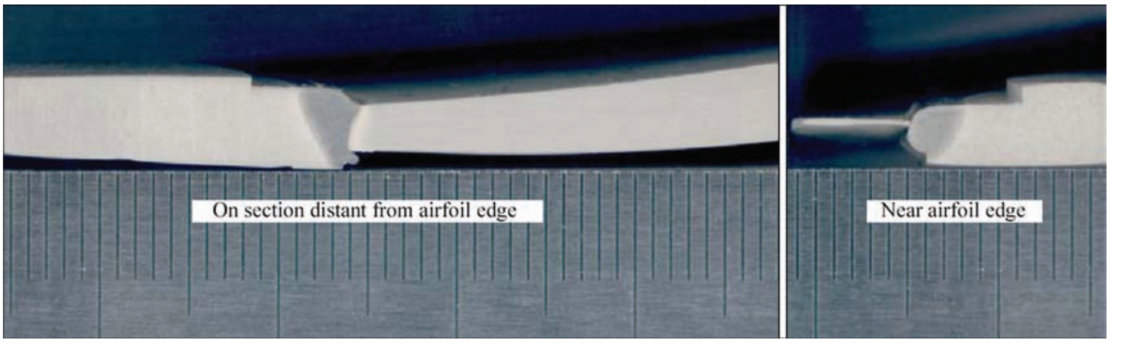

Figure 2. Macrosections of repair EBW-joint of «welded-in piece» and blade airfoil

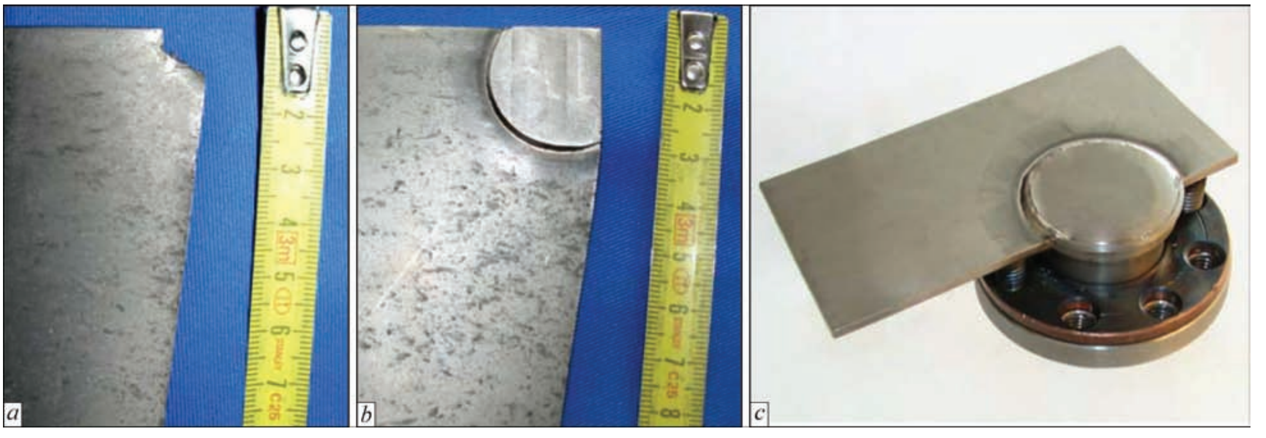

Figure 3. Repair of spot defects of angle of blade airfoil using cylinder repair «welded-in pieces»: *a* — damaged angle of blade before repair; *b* — repaired angle (ends of «welded-in piece» after EBW); *c* — assembly-welding fixture for EBW of cylinder «welded-in pieces» (blade simulator)

fects of airfoil leading edge of different size titanium blades, namely fan blades and blades of GTE LPC.

The following scheme of repair «welded-in piece» and blade airfoil welded joints was developed. It in principle does not depend on the fact whether it is spot or extended defects (Figure 1).

In all cases the joint is carried out by a single-pass EBW, and smooth (without undercuts) transfer from «welded-in piece» surface to base metal is provided by moderate concentration of the electron beam as well as sufficient quantity of additional metal due to applied structure of welded joint with «overhanging shoulder». Moreover, such a smooth transfer can be reached in the areas with sufficiently larger airfoil thickness as well as in the thinnest places adjacent to the edge (Figure 2).

The repair technology was mastered for three types of airfoil blade defects, i.e. spot damage of the blade angle, spot damage of the edge of blade airfoil main part as well as extended local defects of the edge starting from blade angle.

Repair of both types of spot defects is carried out using cylinder «welded-in pieces» (Figures 3 and 4). There are several dimension types of diameters depending on size of airfoil edge defect.

Figure 4. Repair of spot defects of main part of blade airfoil edge using cylinder repair «welded-in piece»: *a* — cylinder repair «welded-in piece» at airfoil edge (its edge was cut out at initial mechanical treatment after EBW); *b* — pilot batch of GTE LPC blades with cylinder «welded-in pieces» on airfoil blade (before final mechanical treatment)

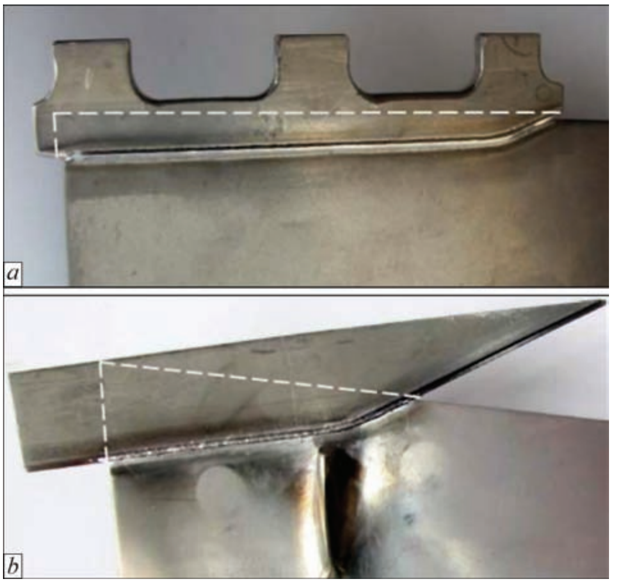

Figure 5. Repair of extended defects of blade airfoil edge: reconstruction of narrow zone adjacent to airfoil edge (*a*); reconstruction of wider zone with very damaged airfoil angle (*b*)

Such a structure is efficient by the fact that matching of diameters of «window» cut out in the blade and «welded-in piece» itself provides fixing and tight contact of butted parts in radial direction. Therefore, sufficiently simple assembly-welding device (Figure 3, *c*) should only provide pressing of the edge of the cut out «window» to mentioned above «overhanging shoulder» as well as holding the whole assembly in space during performance of electron beam pass along the arc of corresponding circumference.

At the beginning the works were carried on the samples simulating real parts. Then the results were successfully tested on the pilot batches of defective blades, provided by SE «Ivchenko-Progress» (Figure 4, *b*).

The corresponding extended «welded-in pieces» are used for the extended defects of different areas of the blade airfoil edge. Their form can be changed depending on width and shape of the damaged zone of blade airfoil edge. In particular, it can be a narrow band replacing only damaged part of the airfoil adge (Figure 5, *a*) as well as «welded-in piece», width of which is very widened to the corner for the case of significant damage of not only the edge, but the angle as well (Figure 5, *b*).

Respectively, uniform pressing of such «welded-in pieces» along the whole length of curved joint with the airfoil requires other more complex assembly-welding fixture (Figure 6).

The developed repair technology was tested on the edges of blade airfoil of different sections and, respectively, dimension types in repair of the defects of various size and shape (Figure 7).

In addition to repair of the blade local damages, it is also important task to replace separate elements

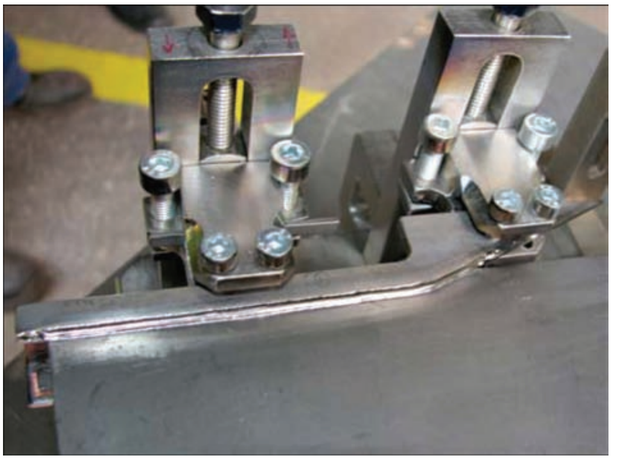

Figure 6. EBW joint of blade airfoil with extended repair «welded-in piece» in assembly-welding fixture

of permanently assembled units of the gas-turbine engine. In particular, such a task was set by Lutsk Repair Plant «Motor».

Guide cases of 3–8 stator stages of high-pressure compressor in gas-turbine engine consist of semi-rings with a set of brazed in them cantilever blades (Figure 8). The blades of 3–6 stages are made of alloy EP-866 (15Kh16K5N2MFAB-sh), and blades of 7, 8 stages are of alloy EP-718-ID (KhN45MVTYuBR-ID); working temperature of the units makes 300–500 °C.

In operation of such engines there are also the cases of appearance of nicks and cracks on the blades as well as their tear out due to local lack of their brazing with the semi-ring wall.

Replacement of the defective blades is allowed following «Engine overhaul manual». At that the defective blade is removed by milling from semi-ring till its wall, including the brazing filler material holding the blade, and this place is filled with an undamaged donor-blade (Figure 9). In other words a completely cleaned section is prepared in the semi-ring for instal-

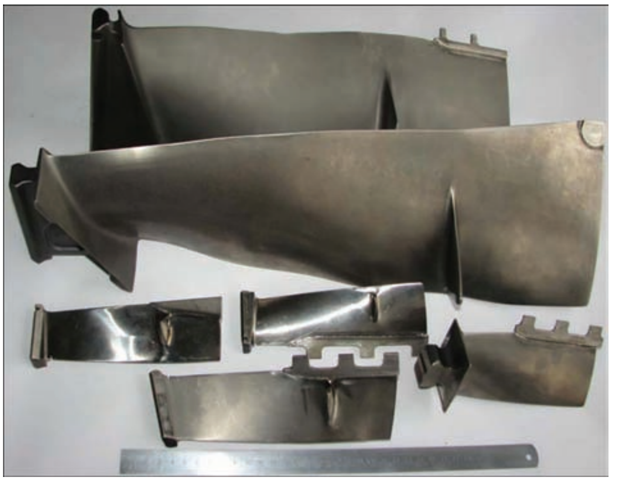

Figure 7. Examples of realization of developed repair technology for different dimension types of the blades (large — fan sections, small — LPC) as well as shapes and extension of airfoil edge defects

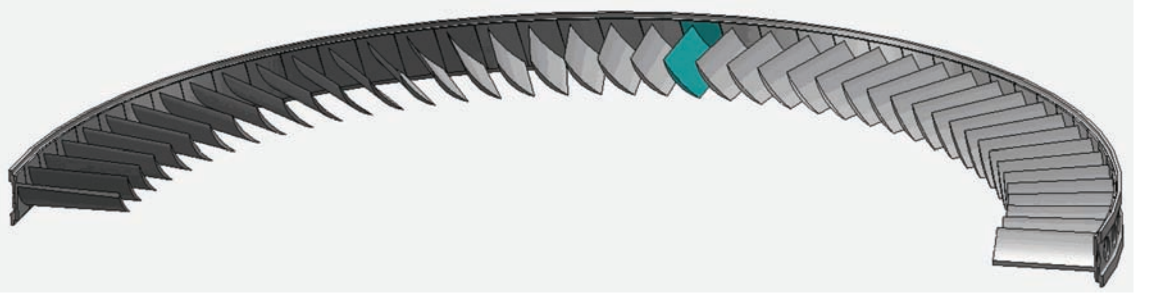

Figure 8. Scheme of semi-ring of stator guide case with set of brazed-in cantilever blades

lation of the donor-blade. It is obviously impossible to repeat initial brazing process without effecting adjacent still suitable blades. Therefore, a fixing method is necessary having local and concentrated temperature effect on the whole assembly unit. Previous technology for donor-blade fixing assumed application of argon-arc welding with the next dressing of weld reinforcement in order to reconstruct the geometry of end of the guide case semi-ring. The disadvantages of such a technology were significant distortion of product shape as well as small penetration depth and, as a result, insufficient area of joint zone, remaining after weld reinforcement treatment and, thus, high probability of tear of the replaced blade during engine operation.

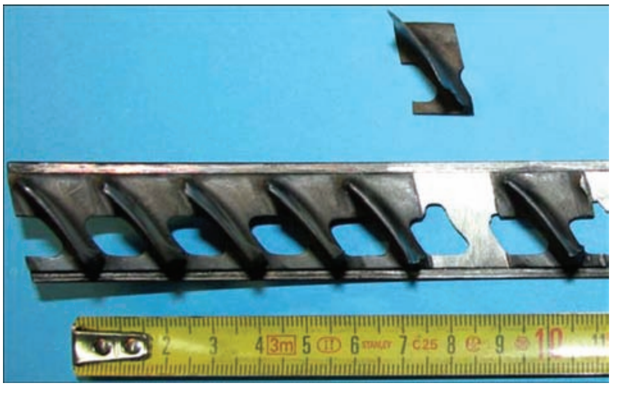

Figure 9. Semi-ring with prepared area for cantilever donor-blade installation

EBW method is ideal in this case allowing receiving the reliable welded joint of sufficient depth in comparison with small heat input in the product being welded.

The next scheme of welded joint of donor-blade and wall of semi-ring guide case was developed (Figure 10). Joining of the blade with wall is carried out using double-side EBW with intermediate turning of the product by 180°. Structural strength of two similar welds is enough for reliable fixing of the blade, which is not inferior to brazed ones.

Taking into account that this is a stator (i.e. immovable) part of the engine, it is not necessary to use extremely high requirements to geometry accuracy of donor-blade setting. Therefore, it is no need in very complex assembly-welding fixture that is usually the most expensive part when using EBW. Developed laboratory fixture (Figure 11) provided sufficiently accurate regulation of spatial orientation of the donor-blade and its reliable fixing in further welding. Later on the Customer got the design documentation for commercial variant of such a fixture for repair of the semi-rings of guide case installed on EBW machine of KL-188 type.

The main process problem, related, in particular, with the peculiarities of EBW method, was possible gaps in the joint between the semi-ring wall and do-

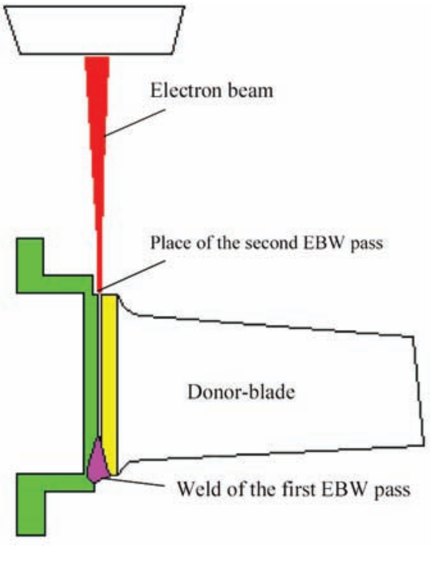

Figure 10. Scheme of double-side EBW of donor-blade with wall of guide case semi-ring

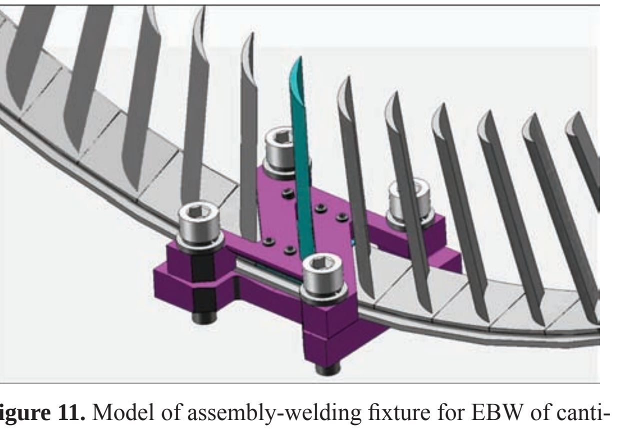

Figure 11. Model of assembly-welding fixture for EBW of cantilever donor-blade with guide case semi-ring

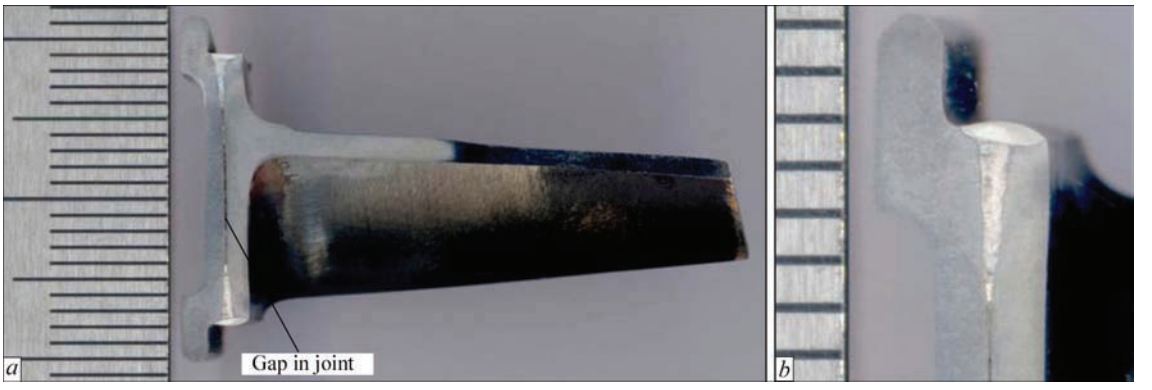

Figure 12. Macrosection of cross section of EB-joint of blade with guide case semi-ring received at up to 0.1 mm gap in joint (*a*) and section area containing the weld itself (*b*)

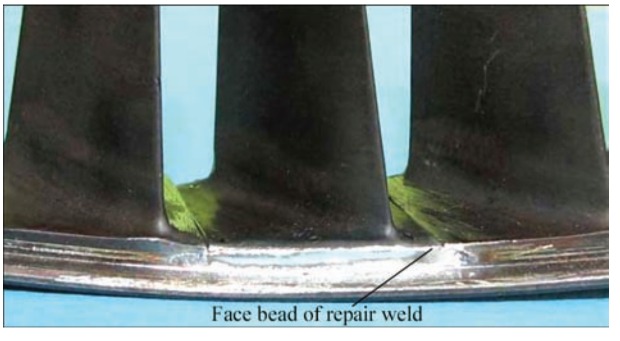

Figure 13. View of repair joint from end of guide case semi-ring

nor-blade base. It is a result of difficulty of local mechanical removal of the damaged blade and formation of the area for the donor-blade. Such gaps are very critical, since thickness of the wall, to which the blade is welded, makes only 0.5 mm in some places.

The results of the experiments, carried out on the sample-simulators, provided the optimum compromise between the power parameters of the electron beam and possibility to form sufficiently deep weld in a thin-wall joint at gap presence in the butt. At that, pulsed EBW mode was used for improvement of weld formation and reduction of total heat input. This allowed getting quality joining of the parts at local gaps in the joint up to 0.1 mm. Then, selected EBW modes were corrected on real joints of the blades with semi-ring of the guide case (Figures 12 and 13).

The technology has passed successful test in repair of a batch of real guide case semi-rings of different stages in HPC stator (Figure 14) under laboratory conditions at PWI and later at Lutsk Repair Plant «Motor».

Figure 14. Repaired guide case semi-rings of different stages of LPC stator

1. Beziyazychny, V.F., Strizhov, A.N. (2010) Increase in efficiency of repair of gas turbine engines on the basis of its localization: Refer. Book. *Ingenerny J. s Prilozheniem*, **8**, 52–56 [in Russian].
2. Eliseev, Yu.S., Krymov, V.V., Malinovsky, K.A. et al. (2002) *Technology of service, diagnostics and repair of gas turbine engines*. Moscow, Vysshaya Shkola [in Russian].
3. Krymov, V.V., Eliseev, Yu.S., Zudin, K.I. (2002) *Production of blades of gas turbine engines*. Moscow, Mashinostroenie [in Russian].
4. Moshkin, Yu.B., Eliseev, Yu.S., Poklad, V.A. et al. (2002) *Method of restoration of blades of turbomachines*. Pat. RF 2185945, Int. Cl. 8 B 23P6/00 [in Russian].

Received 06.10.2017