The upgrade of peen forming equipment for long-sized aircraft parts

A E Pashkov, A Y Malashchenko, A A Pashkov, A A Duk

1 Irkutsk National Research Technical University (INRTU), 84, Lermontova street, Irkutsk, 664074, Russia

E-mail: aa_pashkov@ex.istu.edu

Abstract. This article represents an overview of the main design and technological features of equipment for peen forming and grinding of long-sized parts of the aviation industry. Since the end of the 80s of the XX century, the Federal State Budgetary Educational Institution of Higher Education INRTU has been working on the creation of equipment for the manufacture of large-sized panels and aircraft skins for the leading enterprises of the aviation industry of the Russian Federation. Totally there were 4 industrial units created, which proved their efficiency and competitiveness in the production process of TU-204, TU-334 and BE-200 aircrafts. Based on experience, a universal installation has been developed, which can be used as part of the equipment complex of the industry competence center for the shaping of large-sized aircraft parts.

1. Introduction
An effective method of forming of large-sized panels and skins of aircraft is shot peen forming (SPF) [1-2]. The shot-peen forming process is based on the biaxial elongation of the surface layers by shot treatment. With this effect, the part takes on the shape of a double curvature surface [3-6]. To obtain required form of parts, in foreign practice, such technological methods are used as sequential processing of the outer surface of the part and its longitudinal edges on both sides, as well as the use of deflection, which allows increasing the curvature in the direction of preliminary elastic bending [7-9]. A large number of works are devoted to a comprehensive analysis of the stressed state of a part after shot peen forming using finite element methods [10-15], in which the main advantages of the process under consideration are noted: the formation of a uniform field of residual compressive stresses in the surface layer of the part, which has a positive effect on the product life, the absence of surface faceting and the effect of partial springback of the part after processing, which improves the accuracy of the product shape.

Irkutsk National Research Technical University (INRTU) has a rich experience of interaction with aviation enterprises in the creation of equipment for the implementation of the peen forming technology. Totally, 4 units of the UDF series (shot peening machine) were developed. Common features for all installations of the UDF series is using of the processing concept when the part is installed in the clamps of the fixing device, and the control system moves the working bodies relative to the workpiece and uses the working tools [16] that are in direct contact with the part using elastic seals with different widths:
- a shot-blasting machine for shaping operation. It uses stream of the shots to indent in the front
surface of the part. As a result there is an elongation of the surface layer of the part and, as a consequence, the general bending deformation of the part:

- a grinding machine for ensuring the regulated roughness of the surface layer of the part after processing shot blasting.

These technological features competitively distinguish domestic equipment from foreign counterparts, which use shot-blasting in the closed chambers with an external shot circulation system [17-18]. These installations technologically very complex and expensive. The final shape of the parts is reached only upon completion of the entire machining cycle. In addition, the use of such installations solves the problem of mechanization only of preliminary shaping, and for the final formation of the contour, manual finishing is needed.

2. Stages of development of UDF series installations
The first domestic pilot installation represents a frame portal moving along rails in the longitudinal direction. Vertical feeding is carried out using a hand winch. For this purpose, guides and a movable carriage are provided, on which the transverse movement mechanism is mounted. The latter has cylindrical guides and a manual screw mechanism. The operating experience of the UDF-1 unit served as the basis for further improvement of such equipment.

Installation UDF-2
The development of the model range was the UDF-2 unit, designed for the formation of the first sets of wing panels for the TU-334 aircraft [16]. A general view of the processing unit of the UDF-2 installation, designed to fix and move the working tools of the installation: a shot-blasting machine and grinding machine, is shown in Fig. 1. Its main units are: a movable platform on which a supporting column with vertical and transverse displacement mechanisms are mounted, a control cabinet, two adjustable hydraulic pumps for the main rotation and longitudinal displacement drives. The adjustable parameters are the longitudinal feed rate and the main rotation frequency.

![Figure: 1. UDF-2 installation: 1 - base; 2 - column; 3 - guides; 4 - carriage; 5 - lead screws; 6 - retractable rods of the transverse movement mechanism; 7 - supports; 8 - sliding nuts; 9 - drives for vertical and transverse movements; 10 - operator panel; 11 - control panel; 12 - hydraulic pump; 13 - working tool; 14 - pressure sensor; 15 - fence](image)

Constant contact of the sealing device of the shot blasting machine with the treated surface is maintained using one contact pressure sensor responsible for the transverse movement of the seals of the working bodies.

The basic unit of the fixation system (Fig. 2) is a cross-beam containing clamping elements designed to fix the workpiece.
Exploitation of the UDF-2 unit in pilot manufacturing revealed the following disadvantages:

1. The arrangement of the processing unit with a fixed bearing column limits the technological capabilities of the installation - the magnitude of the transverse displacement of the working bodies and causes the occurrence of self-oscillations of the unit while peening a part.

2. The use of a hydraulic drive for the main rotation of the working bodies does not allow the use of a feedback device on the frequency of their rotation, which limits the accuracy of the shot speed control and does not allow controlling the metal removal during cleaning.

3. Fixing the part in the longitudinal contour is highly labor intensive and requires a special control equipment outline templates of longitudinal section.

4. Pressure control at one point limits the ability to process surfaces with a radius of curvature less than 4 m.

Installation UDF-3
The next stage of development was UDF-3, designed for serial technological process of forming panels and skins of the BE-200 aircraft (with dimensions up to 40 × 1200 × 12000 mm) and introduced at the Irkutsk Aviation plant. A general view of the processing unit of the UDF-3 installation is shown in Fig. 3.
The layout solution of the UDF-3 installation includes vertical feed drive of the working tools, that fixed on the movable bearing column. This makes possible to reduce the overturning moment, prevent the occurrence of self-oscillations and use the high-resource 2D400M shot-blasting machine as a working tool for the forming operation. The processing unit of the installation includes a movable platform on which a longitudinal movement drive mechanism is installed, a column of vertical feeds with a mechanism for its transverse movement; dust collection unit, power electrical cabinet and CNC system panel.

Electric motors were used as drives for longitudinal, transverse and vertical movement. A manual mechanism for tilting the working tools was added, which is a worm gear pair.

The pressure control is carried out in the same way by the contact method, but already at eight points.

Depending on the position of the device rods, control system generates the following operating modes: "Normal mode" "Movement in the transverse direction".

The panel fixation system on the UDF-3 unit consists of 12 lateral movement mechanisms that fix the part at the upper and lower points of the cross sections (Fig. 4). To reduce labor intensity and increase the accuracy of tuning to a given contour, a helical gear and a counting ruler are introduced into the design of these mechanisms.

Figure: 4. Mechanism of lateral movement of the fixation system of the UDF-3 installation: 1 - workpiece to be processed; 2 - emphasis; 3 - clamp; 4 - rack; 5 - screw mechanism; 6 - brace; 7 - base; 8 – frame

Many years of research, as well as taking into account the accumulated experience, the increasing modern requirements for the type of aircraft parts being processed, general directions of development for the modernization of this equipment were formulated [19]:

1. Introduction of a modern control system with the possibility of a backup increase in the number of simultaneously performed functions, as well as an active feedback system during processing.

2. The design of the installation and its elements must ensure the prevention of the occurrence of self-oscillations in all operating modes of the working body (shot blasting machine and / or stripping head).

3. The design of the installation should be of sufficient rigidity to resist changing operational loads and to ensure consistency of accuracy and repeatability of the processing process.

Installation UDF-4

The UDF-4 installation was created to eliminate the disadvantages of the previous models (Fig. 5)
It is using the layout solution of UDF-3. The main differences are:
- using of high-precision linear and circular movement systems based on rolling guides, ball-screw drives, planetary gearboxes, couplings and other mechanical elements of increased rigidity and accuracy of movement produced by leading world manufacturers;
- using CNC system to control the four-axis positioning of the working body relative to the part;
- reinforcement of the structure to reduce the influence of bending loads, eliminate the counterweight system and increase the resistance to vibration effects;
- adding a drive for turning the working body;
- application of the adaptive clamping system [20].

Figure: 5. General view of the UDF-4 installation: 1 - fixation system; 2 - work piece; 3 - trolley for moving the working body 4 along the rails 5 in the longitudinal direction (coordinate X); 6 - slide with rolling guides, ball screws and drive 7 for moving the working body in the transverse direction (Y coordinate); 8 - racks with rolling guides, ball screws and a drive for moving the working body in the vertical direction (coordinate Z); 9 - drive of rotation of the working body (coordinate A); 10 - flexible cable channel; 11 - electrical panel; 12 - control panel; 13 - dust collecting unit.

A general view of the rack of the UDF-4 parts fixing system is shown in Fig. 6. The design includes the required number of racks, depending on the length and rigidity of the part, each of which fixes the workpiece 2 with the help of the stop 3 and the pneumatic clamp 1, providing a constant position of the cross-section during processing. With the help of a stepping motor 6 and guides 5, the rack moves laterally. The hinge assembly 4 in conjunction with the electric motor 7 is responsible for angular movements to ensure the fixation of parts having a twisted cross-section. The positioning of the racks in the longitudinal direction is carried out by moving them along the guides 8 with fixation with screw clamps.
Figure: 6. The mechanism of transverse movement of the fixation system of the UDF-4 installation: 1 - pneumatic clamp; 2 - part; 3 - emphasis; 4 – hinge assembly; 5 - transverse guides; 6-7 - stepper motor; 8 - longitudinal guides

Installation UDF-5

Due to increasing in the complexity of the geometric shape of the long-sized aircraft parts, their dimensions (width over 2000 mm, length up to 30,000 mm) and shape accuracy, the concept of a new UDF-5 unit was proposed - the most advanced (among of the UDF series) (Fig. 7 -8). This installation should cover the needs of the entire domestic aviation industry in the field of shaping of the long-sized aircraft parts. It is advisable to use it as part of the equipment complex of the industry center of competence for the shaping of large-sized parts. The main feature of the installation is a modular platform design and an additional column for attaching the grinding machine (Fig. 9), which has three translational and one rotational degrees of freedom and is installed on a platform, next to the column for shot-blasting machine, moving along fixing device for the part.

Figure: 7. General view of the UDF-5 installation: 1 - shot blasting machine; 2 – grinding machine; 3 - column for the shot blasting machine; 4 - additional column for the grinding machine; 5 - movable platform; 6 - fixing device; 7 – part
Figure: 8. Electronic model of the UDF-5 installation

Figure: 9. Modular design of the UDF-5 platform: 1 - platform and column for the grinding machine; 2 - platform and column for attaching the shot-blasting machine; 3 - platform for servicing the grinding machine; 4 - operator platform; 5 - platform for servicing the shot blasting machine.

The shot-blasting machine module design is shown in Fig. 10. This solution provides the ability to move the working tool to the height required for forming a part with a width up to 2000 mm.
Figure: 10. The shot-blasting machine module design: 1 - shot-blasting machine; 2 - rotary base for attaching the shot-blasting machine; 3 - rack of vertical feeds; 4 platform; 5-6 - substrates for vertical and lateral movement guides; 7-8 - guides for vertical and lateral movement; 9-10 - carriages of vertical and lateral movement.

Structural analysis using the finite element method has shown sufficient static strength of both individual units and whole installation (Fig. 11).

Figure: 11. Examples of distribution of residual stresses (von Mises) in platform and column.

The automated fixation system of the UDF-5 installation is structurally similar to the previous model, but it provides the ability to fix parts up to 2000 mm wide, up to 20,000 mm long and includes:
- base columns;
- support frame;
- racks for fixing the part in the amount of 24 pcs., each of which includes a vertical guide with a tilt unit; pneumatic clamping devices (clamps) moving along the guide (2 pcs.); transverse movement mechanism with a controlled electric drive; tilt mechanism with controlled electric drive and feedback.
device;
- a pneumatic system that supplies compressed air to the drive pneumatic cylinders of the struts clamps;
- a device that ensures the linear movement of the racks along the base during the assembly of the part, with a locking mechanism;
- control and power supply system, which includes a power cabinet with placed drive modules and control systems SIMOTION; operator console and industrial computer PCU.

Equipping the device for shot shaping and stripping with an additional stand for attaching the stripping head, equipped with mechanisms for moving the working body along three Cartesian and one angular coordinates, allows you to simultaneously perform shot processing and stripping or clean up after shot shaping without removing the part from the fixing device, which significantly reduces labor intensity and processing time.

The supply of the part fixation system with individual software-controlled mechanisms of orientation in space, allows you to automate the process of fixing the part and control the shaping process during processing.

3. Conclusion
Scientific team of the INRTU has unique competencies in the field of creating competitive equipment for forming long-sized aircraft parts. The experience began to form in the 80s of the last century, which made it possible to create an installation that has no analogues in the world. This installation - UDF-5 is a modern processing complex, which allows to significantly reduce labor intensity and processing time, as well as to increase the accuracy of the shape of the processed parts.

References
[1] Pashkov A E 2014 Technological complex for the formation of long panels and skins based on domestic equipment Izvestiya of the Samara Scientific Center of the Russian Academy of Sciences 1(5) 1528–1535
[2] Andrey E Pashkov, Aleksander Y Malashchenko, Aleksander A Pashkov and Tatiyana V Zarak 2018 Parameters identification for combined forming of complex shaped sheet metal components Advances in Engineering Research 158 323–329
[3] Baughman D L 1984 An overview of peen forming technology Proceedings of the 2nd international conference on shot peening 28–33
[4] Ebenau A, Macherauch E 1987 Influence of the shot peening angle on the condition of near–surface layers in materials Proc. 3rd conf. shot peening (ICSP3)/253–260
[5] Gardiner T S and Platts M J 1999 Towards Peen Forming Process Optimization Proc. 7th Conf. Shot Peening (ICSP7)/235–243
[6] Gariépy A, Miao H Y and Lévesque M 2014 Peen forming Comprehensive Materials Processing 3 295–329
[7] Badrinarayan P Athreya, Narendra P Singh, Lingyun Pan and Wei Huang 2012 Computational approach for fatigue life prediction in shot peened welded specimens Welding in the World 57 5 675–684
[8] Baragetti S 2001 Three–dimensional finite–element procedures for shot peening residual stress field prediction International Journal of Computer Applications in Technology 14 3 51–63
[9] Barrett C, Todd R 1984 Investigation of the effects of elastic pre–stressing technique on magnitude of compressive residual stress induced by shot peening of thick Aluminum plates Proceedings of the 2nd international conference on shot peening 15–21
[10] Meguid S A, Shagal G, Stranart J C, Daly J 1999 Three–dimensional dynamic finite element analysis of shot peening induced residual stresses Finite Elements in Analysis and Design 31 3 179–191
[11] Miao H Y, Larose S, Perron C, Evesque M 2009 On the potential applications of a 3D random finite element model for the simulation of shot peening Adv. Eng. Softw 40 1023–1038
[12] Wang T A, Platts M J, Levers A 2006 Process model for shot peen forming Journal of Materials Processing Technology 172 2 159–162
[13] Pashkov A E 2013 On increasing the efficiency of the contact type shot blasting machine Proceedings of Irkutsk State Technical University 10(81) 46–52
[14] Pashkov Andrey E, Pashkov Aleksander A and Koltsov Vladimir P 2017 Complex method of peen forming and shot peening of aircraft structural components Advances in Engineering Research 133 585–591
[15] Pashkov A E, Yu Malashchenko A, Pashkov A A, Bogdanov K V and Kryuchkin A V 2019 Development of digital manufacturing technologies for frame and casing parts Materials Science and Engineering 632 012104 1–16
[16] Pashkov A E 2005 Technological connections in the process of manufacturing long sheet metal parts Mater. Sci. 5–22
[17] Horowitz Z I 1979 Das «Shot Peening» - verfahren, seine Grundlagen, Begriffe und die MeS-Methoden zugehörigen Fachber. Huttenprax. Metallweiterverarb 3 174–181
[18] Vaccary J A 1985 Peen forming enter the computer age American mechanist June, 6 91–94
[19] Gavrilov A S 2011 On the creation of an automated contact-type installation for shot-impact shaping and stripping of long panels of aircraft Materials of the All-Russian scientific and practical seminar with international participation 111–117
[20] Likhachev A A, Pashkov A A and Gerasimov V V 2015 Implementation of the control system for the process of shot-impact shaping on contact-type installations Proceedings of Irkutsk State Technical University 2 42–47