Peculiarities of making bolt and rivet connections with interference when assembling the aircraft MS-21

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Abstract. In this paper the peculiarities of installation of fasteners with tension during assembly of MS-21 aircraft are considered. In particular, we considered the aspects of the necessity of using bolt and rivet connections with tension during the assembly of the aircraft fuselage. We have developed a finite element model of the installation process with the rivet bolt in the hole of the package using the system of finite element analysis Simufact. We used the Elastoplastic Concept of Material Behaviour with Nonlinear Hardening Section. And obtained the characteristics of the stress-strain state of the bolt-ribbon joint elements at various moments of rod retraction, including at the predicted moment of shank tear off. It has been revealed that it is expedient to bring the retraction force up to the value close to destructive one. Determined the residual deformations after removal of axial load from the rod. It is proved that it is necessary to actualize the existing normative and technical documentation with specification of the value of the tool impact force on the rivet bolt rod.

1. Introduction
For the production of MS-21 aircraft in the assembly and assembly industry, various types of connections are used, both detachable and fixed. One of the most common types of joints is riveting, bolt riveting and bolt joints, which make up to 90% of the total number of joints of parts [1, 2, 3], as well as in all aircraft. When assembling the MS-21 aircraft, impact riveting technology is prohibited, and in the absence of approaches for the assembly of parts, bolted and riveted bolt connections are used. In particular, most commonly used when connecting the panels along the longitudinal joints in the process of assembling the compartments (Fig. 1) and when connecting the panels along the orbital joints in the process of assembling the fuselage (Fig. 2), bolt-ribbing and, less often, bolted joints.
Figure 1. Location (a) and typical design (b) longitudinal jointing of MC-21 aircraft

Figure 2. Location (a) and typical design (b) of the orbital joints of the MC-21 aircraft compartment

The design of the stud bolt and bolt connections varies depending on the type of rod and bolt head, the size of the head, the material used for the fixing element, and the method of installation in the hole. Examples of rivet and bolt connections are shown in Figure 3 [7].
As a rule, an aircraft's overall resource is determined by the definition of its frame resource. In case of damage to the frame, failures occur that make up 12...30% of the total number of failures [3, 4]. The main cause of failures in most cases is fatigue damage, which occurs at the joints of parts and assemblies [3, 5, 6].

Connection weariness is determined by the following factors [8]:

- peculiarity of the aircraft design and rationality of power configuration (number of rows of fasteners and distribution of loads between them);
- the value of stresses in the elements of the junction;
- the peculiarity of the assembly process (in particular, the axial and radial interference in the connection).

In order to reduce the stress concentration and slow down the development of fatigue crack in the design of the aircraft, the requirement to create a certain stress-strain state of the material in the contact zone of each point is laid down. For this purpose, it is necessary to ensure the formation of technological residual stresses of compression by plastic deformation in the places of supposed destruction [3].

It is established [5, 9-15] that the increase of axial tension in combination with radial leads to the increase of endurance of the parts connection. The value of the relative radial tension is calculated by the formula

$$\Delta = \frac{d_b - d_o}{d_o} \cdot 100, \%$$

where $d_b$ – bolt diameter, mm; $d_o$ – hole diameter, mm.

When manufacturing MS-21 aircraft it is necessary to meet the requirements for radial tension of bolt and rivet connections of about 1.2%. The MC-21 aircraft is designed with a sufficiently large number of bolt rivet joints with tension (about 100,000 domestically produced units per aircraft).

Despite the rich experience of bolt rivet joints in the design of aircraft, some features of the process physics in the performance of these compounds remain poorly understood.

The variety of normative and technical documentation and its mutual contradictions, as well as its obsolescence, do not always allow to perform bolt riveting connection in accordance with modern recommendations. One of the problems encountered is the tear-off of the shank when retracting the rivet bolt pin. This prevents the recommended axial tension in the rivet bolt connection from being achieved.

Figure 3. Design of the bolted (a) and rivet bolt (b) connection of the MC-21 aircraft compartment
and does not allow for the maximum use of the technological endurance potential. In this connection, under the conditions of toughening requirements to the parameters of technological processes, theoretical and experimental studies of the processes of performance of such compounds become relevant again.

In order to ensure the required assembly parameters of the aircraft, set by the designer, the modern technological design cannot be done without the use of CAD/CAM/CAE systems.

Modern systems of engineering analysis help to make the right decision in the choice of technological equipment at the stage of technological preparation of aircraft construction.

In order to increase the fatigue life of joints, the bolt-ribbing technology on MC-21 aircraft consists of three stages [5]:
- 1 stage – hole formation;
- 2 stage – rivet bolt retraction;
- 3 stage – compression of the rivet bolt rings and removal of the shank.

This paper describes the process of installing the rod into the interference hole as shown in Figure 4 [16].

- the grippers begin to retract the rod into the bag opening
- the grippers begin to retract the rod into the bag opening
- rod fully retracted, head seated in socket, bag gap selected
- the tool grips open and the rod tail is released
- the tool grips return to their original position

**Figure 4.** Process of retracting the rivet bolt connection rod of MC-21 aircraft

2. Methods and results
To determine the parameters of the stress-strain the condition required to find solutions to ensure fatigue performance of connections, as well as for the theoretical determination of the rod retraction force, in
this paper. Modeled the process of rod retraction into the hole using the system of finite - of Simufact's elemental analysis.

The geometry of the model is shown in Fig. 5.

![Figure 5. Rivet bolt design model](image)

Geometric parameters of all elements in the model are executed in accordance with the parameters of real elements, determined by the normative and technical documentation at the Irkutsk Aviation Plant in the production of aircraft MC-21.

These parameters can be summarized as follows. The package is represented by two fragments of 1 mm thick sheet parts made of aluminum alloy D16AT. The rivet bolt rod has a nominal diameter of 4 mm and is made of titanium alloy BT16. The model of cams is executed with idealization of the cam mechanism of the tool applied at installation of bolt rivets. This idealization is that the cams are represented by one cylindrical body, while the cams of the real cam mechanism are made in the form of sectors with an angle of about 120 degrees. The length of the sleeve is chosen so that it transmits the compressive force to the bag at the side of the tool tip support surface and the position of the cam's annular knurling relative to the rod so that the shank is gripped by the cam. It should be noted that the holes in the package and the parameters of the rod are not built according to the nominal dimensions, but according to the average values of the tolerance fields, which are defined by the design and normative-technical documentation, in particular, the hole in the package has the size Ø4H7. This is done to ensure that the contact conditions in the model are such that they correspond to the original ones.

The characteristics of the materials were specified using the Elastoplastic Concept with a non-linear section of hardening. Such a conception is the most exact match to the real behavior of the material at elastoplastic deformation. This was specified for sheets, rods and bushings. The cam and the nozzle are simulated by absolutely rigid bodies.

Simufact's calculations have yielded the following results.

Fig. 6 shows the equivalent stresses at different moments of the rod retraction process from start to end. The end torque corresponds to the release of the rod from the cam when the latter is moved by 4 mm from the starting position.
On the fig. 6 the bushings are displaced (second and third position). This can be explained by the distortion of the plane of contact of the package with the upper end of the bushing as a result of the sheet tensioning, as well as by the fact that the bushing is planted on a rod with a gap. The displacement of the bushing and its inclination favors the growth of the tension due to the weakening of the support. Further retracting the sleeve position is slightly aligned, but the wedge-shaped gap between the sleeve and the package does not disappear.

On the fig. 7 the field of equivalent voltages is shown at the moment when the shank of the rod is to be detached. This torque is determined by the value of the stresses in the stem neck at the level of 1200 MPa, which corresponds to the strength limit according to the normative and technical documentation on the bolt rivet rods made of BT16 material. Taking into account the neck diameter of 1.8 mm and the neck area of 2.54 mm², the tear-off force can be approximately determined as $2.54 \times 1200 = 3000$ N. Therefore, it can be recommended that the axial force on the tool cam should not exceed 3000 N. At the same time, if the axial force is less than 3000 N, the desired axial interference will not be provided, as can be seen from the figure. 7 and 8. On the fig. 7 it is visible that tensions in a rod in a contact zone with a package make from 300 MPa on edge of a head to 1000 MPa on a site of transition of a head to
a cylindrical part. In the sheet there are stresses of about 200 MPa. In the previous moment of calculation, differing on axial position of a cam on 0.11 mm, tensions in a rod in a contact zone with a package make from 100 MPa to 800 MPa, that is appreciably less, as shown on fig. 8.

Figure 8. Stress-strain state with cam axial position 0.11 mm less than when the shank is torn off

After detachment of the shank and removal of the pulling load from the rod, we observe the stress field shown in Fig. 9. The tension level in the contact zone of the rod with the package has changed. Now the stresses in the rod are from 100 to 400 MPa, and in the package - from 150 to 250 MPa.

Figure 9. Stress-strain state after the shank has been torn off

It should be noted that such a level of stress will occur when retracting the rivet bolt rod with a force as close as possible to the damaging force. If the retraction force of the rod is less, the stress in the contact area will be less, which will not increase the endurance of the connection as much as it is possible to do technologically.
3. Conclusion
In the course of the presented researches of the process of installation of a bolt rivet rod in a hole of a package the necessity of rationing of force of retraction from the tool side in narrow enough range is revealed. Stress fields obtained on the finite element model at various moments of the rod retraction process are expedient for such rationing, as the excess of force leads to early detachment of the rod shank, and the insufficient force does not provide the necessary completeness of the axial tension for the maximum possible technological increase of the endurance of the connection. Furthermore, the force value cannot be constant over the entire retraction range. Attention also needs to be paid to the duration of the tool’s action on the rod as it is suggested that a destructive force can be applied, but within a certain period of time, when the shank will not detach, the axial tension will increase slightly. As mentioned above, there is a noticeable difference in stress levels in the contact zone of the rod with the package for cam positions that differ axially by only 0.11 mm.

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