Mechanization of forming and levelling of frame and casing parts

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Abstract. The machining of parts reinforced with ribs may lead to deformations expressed by two-axis bending and twisting. An effective method to eliminate such deviations is rolling, which unlike pressing, excludes cracking of aluminum alloys [1-3]. The developed set of manual rolling tool allows processing ribs and blades of a part to receive deformation in two planes. The development of levelling technology that includes mechanized rolling unit and software for automated calculation of process parameters of rolling seems quite promising.

1. Introduction

At Irkutsk Aviation Plant rolling is part of technological production of low-rigid parts reinforced with ribs at the stage of their forming and levelling after machining to receive (eliminate) the required deformation [4]. The processed parts include panels, longerons, beams, frames, ribs, bends, etc. mainly made by milling from thermally strengthened plates and profiles of aluminum alloys. Basic purpose of such parts is to form a load-bearing structure and aerodynamic contour (panel) of aircrafts. The parts subjected to processing generally represent thin-walled cases and beams with symmetric, asymmetric and asymmetrical cross sections. Their design implies such elements as “Cloth” and “Rib”. Figure 1 shows standard milled parts of aircrafts.

2. Levelling methods

There are some foreign works on analytical accounting of deviations in aluminum parts caused by redistribution of residual stress resulting from forming [5-8] and development of techniques of finite-element modeling of considered forming operations [9-12]. The developed method of levelling [13] includes serial processing of ribs and a cloth by rolling, at the same time their pressing force depends on eliminated bending deflections in two mutually perpendicular planes and angles of torsion of cross sections relative to each other. Before defining components of required deformation of a rolled site the deviations in control points located with a certain step along a cloth and ribs of a part are initially measured by coordinate measurement machine. Then the necessary stretching forces and point coordinates of their application are calculated based on received components. The available calibration charts of applied rolling units and stretching forces are used to calculate the required tightening torque of power bolts or pressure in hydraulic cylinder of a tool. Such charts contain dependences received on sample plates for various processed materials at single and consecutive loadings.
The disadvantages of the developed method used to calculate process parameters include high requirements to qualification of engineers and high labor input. These disadvantages can be eliminated by specially developed software [14] consisting of two functional modules. By means of the electronic analog and checking protocol the first module allows creating geometrical characteristics of a part required for calculation on a coordinate measurement machine. After choosing the processed sites of a part and indicating possible places of applying the stretching forces determined by a tool design of each site in cross sections the second module allows calculating process parameters. The developed software allows increasing the accuracy of calculation and reducing the number of deformations thus considerably improving the quality of manufactures pieces.
The unit makes it possible to implement two machining patterns:

1) for large-size parts such as panels – with relocation of a working tool coordinated with rotation of rollers in relation to motionless part, for example, placed in equipment;

2) for light parts such as beams and profiles – with movement of parts along rolling table in relation to a working tool fixed in required position with self-tightening at rotation of rollers.

| Table 1. Main technical specifications of the unit |
|-----------------------------------------------|
| Dimensions of parts processed on the unit, mm: |
| - width (max) | 500 |
| - base thickness (cloth) | 2…25 |
| - rib thickness | 2…15 |
| Dimensions of parts processed beyond the unit, mm |
| - width | 1500 |
| - base thickness | 20 |
| - rib thickness | 2…20 |
| Technological processing parameters of parts: |
| Longitudinal movement of a working tool (max), mm | 1000 |
| Long travel speed, m/min | 0…10 |
| Compressed roller force (max), N | 25000 |

The working tools of the unit represent replaceable rolling heads that differ by their function regarding the processing of different structural elements of a part (straight, L- and T-shaped ribs, a cloth). Figure 4 shows the rolling head for processing of straight ribs, which has driving rollers 1 installed in case 3 and ram 4 on rolling bearings and the mechanism of their loading 2. To rotate the rollers 1 the electric motor 5 of DAT42671 brand (220V, 10900 rpm) with planetary reducer 6 (gear ratio i=510) is used and the rotation from which through spline 7 is transferred to a gear wheel 8 and through parasitic gear wheels fixed in a rocking device (not shown in figure) to gear wheel 9. Gear wheels 8, 9 are also fixed in case 3 and ram 4, respectively, on rolling bearings and are connected to rollers 1. The power single plunger hydraulic cylinder of bilateral action 10 connected to ram 4 by hook 11 is used for compression of rollers 1. At compression the pressure is supplied via choke 13, for reverse motion – via choke 14. The compression force of rollers is controlled on manometer 12 of MP2-UF brand (250 kgf/cm²) fixed on a case of a rolling head. The rollers are made by replaceable diameters of 32 and 64 mm.
The multiplier (pneumohydraulic booster) shown in Figure 5 and Table 2 is used to create the necessary pressure of working fluid in hydraulic cylinder of a rolling head by strengthening the input air pressure.

![Figure 4. Rolling head](image)

Figure 4. Rolling head

![Figure 5. Multiplier](image)

Figure 5. Multiplier

| Table 2. Technical specifications:                      |      |
|--------------------------------------------------------|------|
| Pressure in compressed air network, kgf/cm²             | 5    |
| High pressure of working fluid, kgf/cm²                | 240  |
| Low pressure of working fluid, kgf/cm²                 | 5    |
| Oil volume in low-pressure chamber, cm³                 | 120  |
| Displacement of high-pressure oil, cm³                  | 42   |
| Amplification factor                                    | ≈48  |
| Outside dimensions, mm                                 | 340x240x210 |
| Weight, kg                                             | 3    |

3. Principles of operation of the developed unit for forming and levelling

The regulator Camozzi M008-R005 with built-in manometer (not shown in figure) is used to adjust the input and hence the output pressure.

Work at compression – unclamping of rollers of a rolling head is ensured by Camozzi distributors.
with manual and/or automated switching and includes three stages:

1. **Idle run** – creation of low pressure in a hydraulic cylinder and compression of rollers to complete clearance adjustment between them and a processed piece. It occurs at simultaneous supply of pressure via chokes 1, 2 to the multiplier. At the same time piston 5 almost does not move (small upward movement happens due to difference of areas of its top and bottom parts), and the diaphragm 4 moves upwards thus creating pressure in a hydraulic cylinder.

2. **Operating cycle** – creation of high pressure in a hydraulic cylinder of a rolling head. It occurs when pressure is supplied to the multiplier via choke 1 and free air escape via choke 2. In this case piston 5 moves upwards (ball 8 blocks opening in rod 9) thus creating high pressure in a hydraulic cylinder due to the difference of volumes of a cylinder 6 and a glass 7.

3. **Reverse motion** – full unclamping of rollers of a rolling head. It occurs when pressure is supplied to the multiplier via choke 2 and free air escape via choke 1. In this case piston 5 moves downwards, pin 10 runs into stop block 11, ball 8 opens an opening in rod 9, through which oil is supplied and moves diaphragm 4 until full unclamping of rollers.

Figure 6 shows pneumatic-hydraulic circuit.

The distribution of the stretching force caused by processing a structural element “curvilinear rib” depending on a tilt angle is shown in Figure 6 and Table 3.

![Figure 6. Pneumatic-hydraulic circuit](image)

**Table 3.** Notation disclosure.

| Notation | Description                |
|----------|----------------------------|
| AS       | Air handling unit          |
| F        | Filter (suckerma)          |
| OS       | Air-oil lubricator         |
| R        | Pressure regulator         |
| M1, M2   | Pressure sensors           |
| P1, P2   | Distributors               |
| H        | Fluid power cylinder       |
One of the main knots of the unit is the mechanism of longitudinally cross movement of a working tool, which has two options: with rectilinear and lever-type manipulators installed on a common vase (Figure 7). It is intended for movement of a rolling head at its installation and in processing of large-size parts, for movement and fixing – at installation and processing of small-sized parts. To implement two schemes of processing there is a possibility of a 180° turn around vertical axis 1 with clamp 2 installed in it, the required position is fixed via clamp 3. Axis 1 is installed on rolling bearings 4, between which plug 5 is placed in bearing support 6 connected to case 7 by bolts 8. Covers 9, 10 with bolts 11, 12 respectively are fastened above and below the bearing support 6. Movement in longitudinal direction is carried out on table tracks 13, on which linear devices 14 of Rexroth Bosch Group brand connected to case 7 by bolts 15 are installed.

![Figure 7. Mechanism of longitudinally cross movement](image)

The manipulator of rectilinear type for movement in cross direction has two hollow precision steel shafts 16 by Rexroth Bosch Group inserted into ball plugs 17 of Rexroth Bosch Group installed on table track 18. Electrical and hydraulic wires of unit systems are also placed in hollow shaft. The working tool and the multiplier (not shown in figure) together with rectilinear manipulator are placed on different ends of precision shafts 16.

Crosswise movement in the lever-type manipulator is carried out due to change of an angle between levers 19, 20 and fixing by pneumatic clamps 21.

The additional property of the lever-type manipulator is the possibility of processing motionless large-size parts located much higher than the level of a table, for example, fixed in equipment: on a building berth, a control table, etc. The multiplier of this type of manipulator is placed directly on a case of the mechanism of longitudinally cross movement, near the manipulator (not shown in figure). To install the holder of a rolling head the guide 22 fixed on the end of the manipulator is used.

The holder of a rolling head is used to fix the working tool in required position during processing (Figure 8).
The working tool 1 is fixed by two bolts 3 in holder 2 connected to ram 4 by screws 5, 6. When holder 2 is connected with ram 4 in the position shown in Figure 8 this ensures purely perpendicular position of axes of rollers of a rolling head 1 to a table. If there is a need to turn a rolling head 1 around horizontal longitudinal axis by ±45° screw 5 is rearranged into position 7 (combined C-shaped groove of ram 4 and opening of holder 2).

Ram 4 with inserted ball plugs 8 of Rexroth Bosch Group is installed on guide 9 having grooves where the sprung clamp 10 is included to fix a rolling head in extreme top and bottom positions. Lowering of a rolling head 1 is carried out by rotation of handle 11 connected by feed screw 12, on which limiter 13 is installed. Ram 4 is not connected with limiter 13 therefore for their simultaneous lowering it is necessary to pull trigger 14 and to remove clamp 10 of a top groove of a guide 9. The extreme lower position of a rolling head 1 corresponds to clamper input 10 in the lower groove of a guide 9. When rolling the next site of a part at the same height it is necessary to pull trigger 14 and to remove clamp 10 of the lower groove of a guide 9, to lift a rolling head 1 by handles 15 to clamper input 10 in the top groove of a guide 9. After that the site of a part changes, clamp 10 is taken from the top groove of a guide 9 by pressing a trigger 14, the rolling head 1 is put down to contact of ram 4 with limiter 13 and clamper input 10 in the lower groove of a guide 9.

The mechanism has a possibility of rotation of a rolling head around a vertical axis of a guide 9. To avoid rotation while processing and installation of a rolling head in the position shown in Figure 8 it is necessary to connect clamp 16 to ram 4 by screw 17.

Trolley table with guides (Figure 9) is used to place all mechanisms and systems of the unit and its movement in intershop space.
Figure 9. Trolley table cart with guides

There is a possibility to lift wheels 1 by rotation of handles 3 and the unit on support 2 and to regulate the table by height by rotation of handle 4. Two high-precision steel shafts 5 with support rods by Rexroth Bosch Group are used as guides. For convenience when moving from two sides of a table there are handles 6.

The trolley table with rolling surface (Figure 10) is attached to the main trolley table in need of processing of small-sized details directly on the unit, when processing large-sized part out of the unit the trolley table can be disconnected for free transportation in shop space.

Figure 10. Trolley table with rolling surface

For movement of parts there are wireless rolling surfaces consisting of six rollers 1 installed with a step of 320 mm on rolling bearings 7 (external diameter of rollers – 43 mm, length – 450 mm). There is also a possibility to lift wheels 2 by rotation of handles 3 and the unit on supports 4 when performing rolling operations. For convenience of movement the table has handles 5 from two sides.

Along with rolling creating local deformation of stretching it is also advisable to use the method of
changing ensuring local compression to process low-rigid reinforced parts. The combined application of rolling and charging opposite by results of deformation will allow expanding technological capabilities of the process, increasing productivity and excluding failures due to formation of cracks, which is typical for press methods, especially when processing parts from low-plastic aluminum alloys, such as 1933T.

Within the work on creation of such technology the following is planned:

1) To develop a special device for ribs charging – replaceable working tool of UFP-1 unit;
2) To model the process of charging with application of engineering analysis systems;
3) To develop a method of calculation of process parameters for levelling of reinforced parts by charging.

In case of levelling of parts with increased rigidity, where due to their complex configuration press methods are also inapplicable, it is possible to use a flail tool similar to peen forming. Replaceable nozzles of different form and diameter allowing processing various structural elements of a piece serve a working element. The development of combined levelling technology with use of a flail tool and shot peening with predeformation will allow producing parts with enhanced rigidity with high precision of a geometrical form.

Within the work the following is planned:

1) To develop a trial sample of a flail tool for levelling of parts with increased rigidity being a replaceable working tool of developed UFP-1 unit;
2) For expansion of technological capabilities of shot peening UDF-4 unit to install special equipment for forming and levelling of parts with increased rigidity by shot peening with predeformation;
3) To develop the combined technology of levelling of parts with increased rigidity by shot peening with predeformation and a flail tool reducing labor input of levelling and increasing accuracy of part profile.

Another direction of MPD methods is the technology of preventive deformation – peen forming of parts like reinforced cases and walls. The hardening of such parts with high requirements to production accuracy leads to deformations due to asymmetry of cross sections and small rigidity expressed in form deviation by more than 10 mm. The restrictions concerning the usage of elasto-plastic deformation after face hardening requires special processing methods ensuring minimization of possible distortion of parts by controlled predistortion of form compensating undesirable deformations caused by hardening.

4. Conclusion
The increase of accuracy of parts after peen forming can be reached by preventive deformation through rolling, charging, bead-blasting. The technology shall be based on profound analysis of residual stress caused by complex processing.

The combined technology realized according to scheme “Preventive Deformation – Shot Peening” will allow significantly increasing the quality of production of parts like reinforced cases and walls.

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