Developing an algorithm to control the accuracy of the milling of aerospace parts with cellular structure by using copying machine-tools with CNC of “SVO” type

O Pas and N Serkov
Mechanical Engineering Research Institute of the Russian Academy of Sciences, Maliy Kharitoniievskiy per. 4, 119334 Moscow, Russia
E-mail: o.pa88@yandex.ru

Abstract. Milling process of machining aerospace parts with cellular structure by using mirror milling system was examined. Different types of errors during machining were considered. Various techniques of reducing errors were defined.

1. Introduction
So called “waffle shells” are used in supporting structures of aerospace parts. Waffle shell (fig.1) is the part made of aluminium alloy with cylindrical, conical of ogival shape having “cellular” structure, which is the result of the milling of the rows of the cells.

There are several methods of producing waffle shells: 1) chemical milling; 2) mechanical milling of plate workpieces and their bending into shells; 3) mechanical milling of cylindrical workpieces.

The main technology to produce aerospace part with cellular structure is the milling of cylindrical workpieces by using specialized machine-tools of “SVO” type. By using this manufacturing method it is much easier to produce shells with cellular structure with non-uniform stiffness and it is not necessary to use a variety of bushes and fixtures for bending in this case.
2. Producing waffle shell with machine-tool of “SVO” type

There are two key features of the shells with cellular structure, that complicate the milling process by means of productivity and machining accuracy: the large size of the shell and their low thickness. One of the ways to solve this problem is to use the computer numerical control in combination with copying technique in the machine-tool of “SVO” type. On the fig.2 shows the layout of machine-tool for producing the shells with cellular structure by using numerical-copy control of “SVO” type machine-tool. Here: CH1 – copying head, CH2 – cutting head, D1 - copying head drive, D2 – cutting head drive, E1 – position measuring encoder of the copying head drive, E2 – position measuring encoder of the cutting head drive, CNC – computer numerical control unit, W – workpiece. During the machining process of the waffle shells, the cutting head CH2 process the bottom of the cell, while the copying head CH1 traces the opposite surface of the workpiece W. In this case the pass strategy is determined by the part program, whereas the cell bottom thickness is determined by copying the opposite side of the bottom by copying head. The scatter of the cell bottom thicknesses, which is one of the main characteristics of the waffle shell, is significantly reduced by using this technique. Wherein using the computer numerical control together with copying technique can be considered as a new tendency of the development of the CNC systems for the machining aerospace parts with cellular structure.

Figure 2. Layout of the machine-tool for producing waffle shells.

Several main factors, which can affect cell bottom thickness errors, can be distinguished (fig.3) for aforementioned machining process. After several tests it was concluded that cell bottom thickness and cell edge thickness values depend on the position within the cell, cell number within the row and the row number. As a result main factors which affect cell bottom and edge thicknesses although can be divided on two groups: 1st group – the factors that affect the thickness within the single cell, 2nd group – the factors that affect the thickness within the row and within the whole part.

3. Approaches of increasing accuracy

Several fundamental approaches of increasing accuracy of the machine-tools with CNC were considered in work[4]. All approaches were divided into two classes 1) improving the design of the supporting system and numerical control system of the machine-tool and improving the manufacturing technology of producing the machine-tool with CNC; 2) improving the machine-tool control process by developing the correction techniques.
Different correction techniques were examined in work [5], which can be used in improving the machine-tool control process:

- correction techniques that are based on a priori information (correction based on the results of the calibrating of the machine and part program predistortion)
- correction techniques that are based on the feedback loop (control is performed by measuring the output value error)
- correction techniques that are based on the control of the disturbances.

The cell bottom machining accuracy can be significantly increased by utilization of the aforementioned correction techniques with taking into account the main factors, which can affect cell bottom thickness errors, and numerical-copy control of “SVO” type machine-tools.

The latest models of “SVO” type machine-tools are equipped with cell bottom thickness automate ultrasonic measuring system. As a result the measured cell bottom thicknesses data can be used for performing the tool trajectory correction.

The best result could be achieved by usage of the ultrasonic measuring system as a feedback sensor in the real time mode during the machining process. In this case 6 out of 8 factors (fig.3) can be compensated by means of their influence on the machining accuracy of the cell bottom thickness. Redistribution of the inner strains and temperature-induced variations of the machine-tool cannot be compensated by this approach because they are not covered by feedback loop.

It’s a difficult task to implement this kind of correction even by using up-to-date measuring equipment because of the following reasons:

**Figure 3.** Main factors, which can affect cell bottom thickness errors.
bad repeatability of measurements in “dynamic mode” (i.e. measurements during trajectory movement) due to lack of immunity to interference of the ultrasonic measurement system in the plant;
- too much time required for processing the measured data by computer of the ultrasonic measurement system, which does not allow to use this system in real time mode.

Therefore, the ultrasonic measurement system can be used as a part of the self-tuning system in combination with the disturbance control correction technique (fig.4).

Figure 4. Self-tunning correction system.

Self-tunning correction system uses the cell bottom thicknesses data measured after machining the first cell (i=1) for machining the following cells with corrected part program. Thus the deviations from 1st group (fig.3) could be eliminated. During the machining of the following cells the errors, induced by the factors from the 2nd group will take effect. Disturbance control correction technique can compensate part of these errors (induced by the deviation of the spindle axis from normal to the surface and by the inaccuracies in the work of the copy head), the other part of errors can be compensated by self-tunning correction system based on the measurement data after processing the cell number i. Self-tunning correction system in this case calculates the corrections based on the thickness measurements after the machining of the i\textsuperscript{th} cell and defines the number of the next cell, that will be used for taking the thicknesses measurements for the correction of the part program for machining the following cells.

It must be mentioned that the extension of the disturbance control correction techniques functions increases the amount of the cells, that could be machined by using the same corrected part program and thus increases the performance rate of the machining of the waffle shell. Search for the effective way of allocating the functions between the self-tunning correction technique and disturbance control correction technique is a subject of foregoing theoretical and experimental researches focused on developing the algorithm to control the accuracy of the milling of aerospace parts with cellular structure.

4. Conclusions

1. Computer numerical control of the machine-tools is one of the main ways to automate the machinery production, including the aerospace part production
2. Computer numerical control in combination with copying technique can be considered as a new tendency of the development of the CNC systems for the machining aerospace parts with cellular structure with high performance rate.
3. The researches focused on the creation of the effective design of the machines with numerical-copy control and algorithms to control the accuracy of the milling of aerospace parts with cellular structure need to be further developed.

References
[1] Computer-aided manufacturing system for creation of part programs for machining waffle shells. http://niigermes.ru/deyatelnost/reshenie-teknologicheskikh-problem-raketno-kosmicheskoy-tekhniki/item/55-avtomatizirovannaya-sistema-podgotovki-i-kontrolya-upravluyavushchikh-programm-dlya-frezerovaniya-vafelnykh-obechak-na-stankakh-s-chpu-tipa-svo.html
[2] Bartrutdinov R and Sysoev S 2011 Manufacturing waffle shells for aircrafts Actual problems of aviation and cosmonautics vol 1 pp 7 - 8
[3] Kotov A, Chuikin S, Milekhin J, Makarov J, Korotkov A and Volodina S Metalworking machine http://bd.patenat.su/2397000-2397999/pat/servlet/servlet7c1.html
[4] Serkov N 2010 Fundamental approaches of increasing accuracy of the machine-tools with CNC Engineering and Automation Problems vol 2 pp 26 - 35
[5] Serkov N 2015 Accuracy of the machine-tools with CNC: theoretical and practical fundamentals (Moscow: Lenand)