OPTIMIZATION OF FLEXIBLE TOOLING SYSTEMS OF AIRCRAFT FUSELAGE

***[1]Brocke Sedrick Samuel Amar-Ofosuhene, [2]Van-Brocke Susuana Araphua, [3]Baah Noah Kwaku, [4]Yao Francois Michael Kra**

1. College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China.

2. College of Nursing, Volta River Authority, Ghana.

3. College of Computer and Information Engineering, Hohai University, Nanjing 210098, China.

4. School of Science and Engineering, Atlantic International University. Honolulu HI 96813, United States

**Contact:* amar_brocke@yahoo.com

ABSTRACT: *With the continuous progression of the advancement of new age airplane, great, high-productivity, and high-adaptability have become predictable necessities for the gathering of fuselage segments. The customary gathering mode can't meet assembly necessities. As per the fuselage get together undertaking of a particular sort of airplane, this paper investigates the underlying attributes of the fuselage items, takes the situating of the cycle crossing point openings of the skeleton segments as the exploration object, receives the secluded plan thought, and plans a bunch of adaptable frameworks as per the prerequisites of framework capacities and specialized markers. The tooling framework understands the adaptability of the situating of meeting openings of the fuselage outline, establishing the framework for the programmed gathering of the center fuselage parts. The underlying attributes, specialized boundaries and utilitarian pointers of the fuselage segments in the airplane, the item prerequisites for tooling are investigated, four diverse adaptable tooling plans are proposed, and the different plans are gauged and looked at through hypothetical examination and trials. An adaptable tooling test stage was constructed, equipment troubleshooting, boundary setup and program configuration were finished, the movement control of every servo hub was understood, the control plan of the servo framework was checked, and the situating mistake model of the test stage was set up. The instrument adjusts the portable unit of the tooling, positioning accuracy of 0.05mm.*

Keywords: Flexible tooling, center fuselage parts, situating of convergence openings, multi-pivot movement control, airplane gathering

1 INTRODUCTION

As a significant industry, the avionics business isn't simply identified with public guard, yet in addition, advancement of the public economy and improve the degree of logical and mechanical turn of events. In this way, it is important to constantly improve the degree of aeronautics fabricating, advance the change and redesigning of the flight business, and understand the jump improvement of the avionics business. The Chinese government and public pioneers are worried about the improvement of the aeronautics business and raise the flying business to a level identified with the public economy and individuals' occupation. The "Public Strategic Emerging Industry Development "Five-Year Plan" and "Made in China 2025" both view the flight gear industry as Breakthrough improvement in key territories. Lately, with countless forward leaps in center and key innovations, China's flight hardware development has accomplished a high advancement. Regarding common airplane, the huge traveler airplane C919 is going to make its lady flight and the provincial airplane ARJ21 will be placed into business activity. Following the nation's progressive opening of the low-elevation region, the public's craving for little and medium-sized airplane is getting more and more grounded. The overall aeronautics industry will undoubtedly introduce a quick period of advancement. As regards military airplane, the J-10 and J-11 warriors have been furnished with an enormous number of troops and serialized improvement, understanding the jump from the third-age gear to the fourth-age hardware for the Chinese contenders, spoken to by the J-20 and J-31 warriors. Along with the United States and Russia, China has become the world's fastest contender advancement nation. With the expansion in homegrown interest for civil and military airplane, different new models of airplane have been placed into improvement and creation consistently. The assortment, enormous yield, and short creation cycle represent a major test to the current assembling arrangement of the flight industry [1].

In the face of the new generation aircraft stealth, supersonic cruise, long life and other requirements, countries actively learn from foreign advanced experience. At the same time, combined with the current situation of the industry to carry out research on intelligent manufacturing and flexible assembly systems in the aviation field 2. At present, domestic aviation manufacturing companies use a large number of CNC machine tools in the processing and manufacturing of aircraft parts and components, with high processing accuracy and high speed. However, when assembling aircraft in various assembly plants, some manufacturers still use old-fashioned rigid tooling and workers use manual drilling and riveting. The quality and efficiency of aircraft assembly cannot be improved by another level, and it is difficult to meet the requirements of new aircraft for supersonic cruise, stealth and service life 3. There is still a big gap between China's aviation manufacturing industry and advanced foreign countries, and there is little accumulation in related technologies, especially flexible tooling technology, automatic drilling and riveting technology, flexible assembly system and digital detection technology 4.

New necessities under the new circumstance decide new troubles and difficulties. The current homegrown aeronautics producing industry needs to take care of the accompanying issues:

(1) Market interest for different models, high yield, little clusters, and high worth

With the improvement of the occasions, individuals have increasingly elevated prerequisites for the personal

satisfaction and productivity. Airplanes will be broadly utilized in every day transportation and different businesses. A great number of individuals need to possess and fly their own airplanes accordingly. The future airplane producing market broaden possibilities, which also assessed that from 2015 to 2025, there will be 12,000 mainline airplanes for long reach, 2700 local airplane for short reach, 18,300 broadly useful airplane and 12,000 helicopters around the world. It has a market estimation of US$2 trillion. Simultaneously, with the continuous opening and headway of the homegrown low-elevation field. Individuals are anxious to claim their own airplane, and there is a colossal interest for broadly useful airplanes, helicopters and robots (from "Made in China 2025"). The expansive market request decides the improvement course of flight fabricating organizations. From one perspective, certain airplane are sought after and require quick creation by flight fabricating organizations; then again, in this time of progressively individualized, private customization of airplane will turn out to be increasingly significant. To an ever-increasing extent, this expects makers to be able to change creation in little groups rapidly.

(2) The flexible assembly framework requires supporting tooling innovation

With the advancement of innovation and changes, the necessities for quality, proficiency and execution of the new age of airplane have additionally expanded. In the current assembly mode, the utilization of unbending tooling and manual penetrating and riveting can't well meet the assembling prerequisites of new models, particularly regarding effectiveness. Unfamiliar progressed flight fabricating organizations are confronting the present circumstance and are in the gathering of huge airplane segments. The first to utilize adaptable gathering framework, beat the issues of value and proficiency in airplane assembly. The adaptable gathering framework generally utilizes mechanized boring and riveting hardware, and the unbending tooling structure can't meet the transparency prerequisites of robotized gear. With the wide utilization of CNC machine instruments in the flying assembling industry, complex general outline like parts can be prepared, which advances the improvement of adaptable tooling situating innovation.

The interest of the market and the advancement of existing innovation establish that we should consider adaptable gathering frameworks and create flexible tooling innovation.

1.1 Comparison of the characteristics of rigid tooling and flexible tooling

Table 1 Comparison of rigid tooling and flexible tooling

Characteristic	Rigid tooling	Flexible
Features	Rigid	Flexible,
Operation	Manual	Automatic
product quality	Average	High
dimension chain transfers the way	Analog coordination	Digital quantity transfer

Every homegrown aviation company has its own CNC machine device production line, which can handle basic underlying parts with complex stiffeners with high exactness and solid unbending nature. It not just improves the inside skeleton structure of the airplane but also lessens the quantity of associations between outlines, yet in addition upgrades the uprightness of the item and diminishes the heaviness of the airplane.

1.2 Flexible tooling workflow

This paper basically examines the fuselage assembly of a specific arrangement of airplane. The places that should be situated are for the most part the crossing point openings on the fuselage outline and the fuselage bar, and simultaneously, completely think about the working space of laborers during gathering.

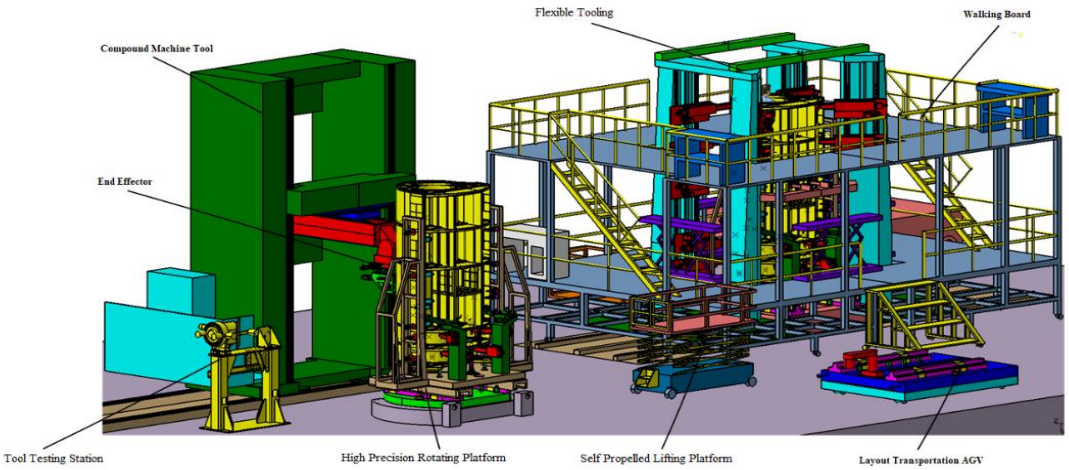

Figure 1: Overall layout

The programmed boring and riveting framework is made out of composite handling machine devices, multi-sensor combination end effectors, adaptable tooling, high-accuracy turning situating table, segment transportation AGV, instrument test station, ground assistant hardware, and so forth, among which adaptable tooling is utilized for body assembly for situating casings and pillars, the fuselage parts are pre-amassed into items by manual procedure on the strolling stage. The parts are moved to the AGV to run the pre-assembled items. Oneself pushed lifting stage helps out

the turntable to help laborers to move toward the airplane parts for establishment and investigating. The exactness turning situating table pivots the item to be penetrated and bolted at a specific point. The end effector should be tried on the device test station prior to boring and arresting and after the device is changed. The composite preparing machine device and the multi-sensor combination end effector should be bored and bolted.

2 Flexible tooling control process

The control cycle of tooling is as Figure 2 shown.

1. The flexible tooling has a sum of 30 controlled engines.
2. The beginning situation of the tooling is in the open state, move the CNC tomahawks X1 and X2 to drive the tooling segment to the predetermined position, and afterward the rail brake will bolt the ground rail.
3. The pneumatic clipping component on the highest point of the gantry cinches, and the third.
4. Install the base layer of the fuselage outline on the base inflexible finder.
5. Move the mathematical control tomahawks Y53, Z53, Y54, Z54, physically change the fifth layer of unbending positioner, lock it when set up, and afterward introduce the fifth layer of the fuselage outline and introduce the vertical bar.
6. Move the mathematical control tomahawks Y43, Z43, Y44, Z44, physically change the fourth-layer inflexible finder locking it set up.
7. Move the CNC tomahawks Y33, Z33, Y34, Z34, and physically change the third-layer inflexibility.
8. Adjust the principle raising shaft positioner and the upper watchman plate positioner, introduce the upper side of the 900 bar.
9. Move the CNC hub Y21, Z21, Y22, Z22, Y23, Z23, Y24, Z24, lock it set up, at that point introduce the second layer of the fuselage outline, introduce the vertical bar.
10. Move the CNC pivot Y11, Z11, Y12, Z12, Y13, Z13, Y14, Z14, lock it set up, at that point introduce the primary layer fuselage outline and introduce the vertical bar.
11. Adjust the drop defenses plate positioner, introduce the lower side of the 900 bar.
12. Return all the positioners on the vertical segment. The third layer of unbending finder section is taken out.
13. X1, X2 hub direct rail brake is delivered, the top storage of the gantry is opened, move X1, X2 hub, open the gantry.
14. AGV streetcar will ensure the tooling and the items are eliminated together, moved to the turntable, and the tooling part is finished.

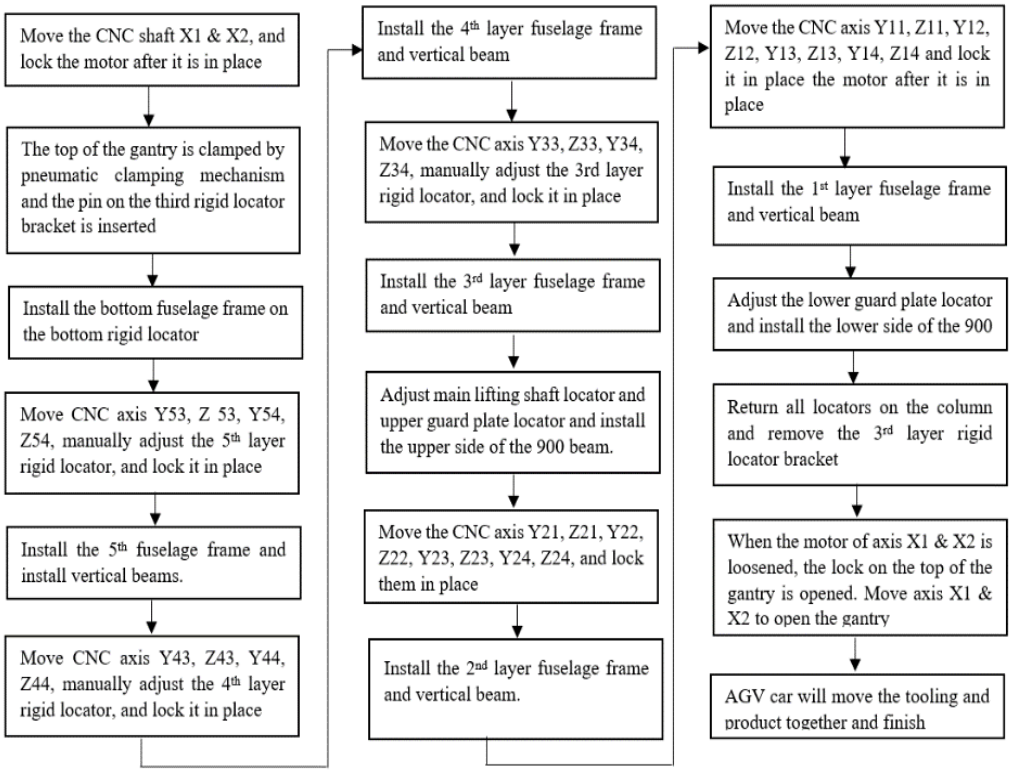

Figure 2: The control cycle of tooling

2.1 Multi-hub linkage control plot

Flexible tooling multi-hub linkage control types, as appeared, it primarily incorporates the linkage control of two tomahawks of one moving unit, four tomahawks of a similar development heading of four moving units, and eight tomahawks of four moving units.

1) Two-pivot linkage

The control of two-pivot linkage is moderately basic. Since one PLC has two rapid yield focuses, it can handle two servo drives. In this way, the linkage between two movement tomahawks constrained by a similar PLC can be acknowledged by the program plan inside the PLC.

2) Multi-pivot linkage

The control of multi-hub linkage is generally muddled, and multi-pivot linkage control needs to consider the correspondence between various PLCs.[6, 3], In request to understand the control of multi-hub linkage. There are by and large two plans in multi-hub control. One of them is acknowledged at the product level.

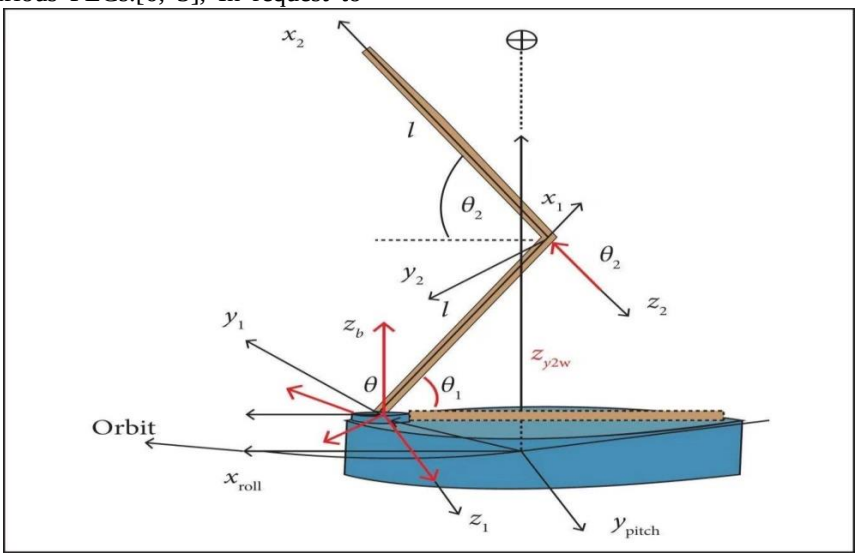

Figure 3: Movement axis linkage classification

3 Force investigation of convergence opening

As indicated by the tooling format and the item computerized model, the hanging length when the actuator arrives at the farthest position, that is, the distance between the middle line of the crossing point opening and the cantilever, is up to 500mm, and the power examination of the convergence opening position [5].

The moving pole is pushed in the vertical way Y built at F_1 Under the action of moving the rod P point at Y Deformation in direction $W_Y = 3.4\times10^{-5}m$, I_Z Is the moving rod section pair Z The moment of inertia of the shaft is based on the formula:

$$W_1 = \frac{F_1 L^3}{3EI_Z} \qquad (3\text{-}1)$$

Where moving rod point at Displacement in the direction, for the load in the direction, is the cantilever length of the moving rod, is the modulus of elasticity, is the moving rod section pair the moment of inertia of the shaft.

The following conditions: Put, the solution of equation (3-1) is:

The moving rod is forced in the horizontal direction Z Set under the action of moving the rodF_2 P point at Z Deformation in direction $W_Z = 2\times10^{-5}m$, I_Y Is the moving rod section pair Y The moment of inertia of the shaft is based on the formula:

$$W_2 = \frac{F_2 L^3}{3EI_Y} \qquad (3\text{-}2)$$

Where W_2 Moving rod P point at Z Displacement in the direction, F_2 for Z the load in the direction, L Is the cantilever length of the moving rod, E Is the modulus of elasticity, I_Y Is the moving rod section pair Y the moment of inertia of the shaft.

The following conditions: $W_2 \le W_Z = 2\times10^{-5}m$,will $L = 500mm, F_2 = 300N, E = 210GPa$, Into the equation (3-2) to solve: $I_Y \ge 298cm^4$.

The moving rod consists of two parts: rectangular steel and guide rail.

If the quality of the guide rail and rectangular steel is not considered, when the intersection hole is stressed, the force and bending moment at point O are: due to the dual guide rail installation, the force-bearing part of the moving rod is two guide rails.

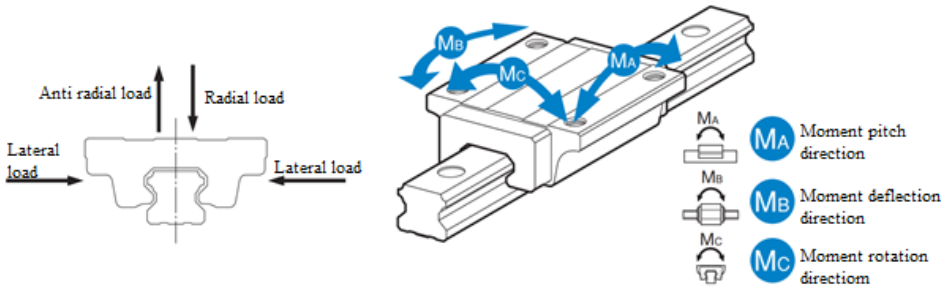

Figure 4: The direction of load on the rolling guide

The force of a single guide rail is:

$M_A = \frac{1}{2}M_Z = 250Nm, M_B = \frac{1}{2}M_Y = 75Nm, M_C = \frac{1}{2}F_1 \times C = 25Nm$,

among them C It is the distance from the center of the positioning pin to the center of the guide rail when the joint is at the farthest point.

(2) Calculation of mobile rod selection

use $100mm \times 80mm \times 12mm$ Rectangular steel, SHS30C guide rails are centered according to the rectangular section Z The formula for the moment of inertia of the shaft:

$$I_Z = \frac{bh^3}{12} \quad (3\text{-}3)$$

Where h Is the height of the rectangular section, b Is the width of the rectangular section?

Rectangular steel section pair Z The moment of inertia of the shaft is: $I_1 = \frac{10 \times 8^3}{12} - \frac{7.6 \times 5.6^3}{12} = 315.4432cm^4$, Each rail on both sides to Z The moment of inertia of the shaft is: $I_2 = \frac{2.8 \times 2.3^3}{12} + 2.8 \times 2.3 \times 5.15^2 = 173.6439cm^4$, Then the moving rod section is Z The moment of inertia of the shaft is: $I = I_1 + 2I_2 = 663cm^4$,The following conditions: $I > I_Z = 574cm^4$.

If the moving rod bears the uniform load of gravity, then P point at Y The direction displacement is based on the formula:

$$W_1^{'} = \frac{F_1 L^3}{3EI_Z} + \frac{qL^4}{8EI_Z} = \frac{F_1 L^3}{3EI_Z} + \frac{mgL^3}{8EI_Z} = \frac{F_1 L^3}{3EI_Z} + \frac{\rho g S L^4}{8EI_Z} \quad (3\text{-}4)$$

Where F_1 Is the vertical load, L Is the length of the moving rod, E Is the modulus of elasticity, I_Z Is the moving rod section pair Z The moment of inertia of the shaft, ρ Is the density of the moving rod, g Is the acceleration of gravity, S Is the cross-sectional area of the moving rod.

will

$F_1 = 1000N, L = 0.5m, E = 210GPa, I_Z = 663cm^4, \rho = 7.8g/cm^3, S = 50.32cm$

Substituting formula (3-4) to solve: $W_1^{'} = 3.21 \times 10^{-5} m$,To meet the conditions: $W_1^{'} < W_Y = 3.4 \times 10^{-5} m$.

therefore, $100mm \times 80mm \times 12mm$ The rectangular steel composed of the rectangular steel and the guide rail of SHS30C meet the design requirements.

4 Experimental Verification

Introduce four laser tracker target ball seats on the base of the test stage, and spot them on them. Four objective balls, in the laser following estimation framework, as per the deliberate information of the four objective balls, the tooling Cartesian organize framework is consequently created. As indicated by the connection between the tooling base and the segment 1, the organize arrangement of the section 1 is set up. As per the guide mistake of the guide rail and the transmission blunder of the lead screw and the rack and pinion, the blunder model is utilized to figure the general spatial mistake, and the mistake esteem is remunerated to the control framework. The situating exactness of the portable unit when blunder remuneration is estimated by a laser tracker to confirm the accuracy of the mistake model.

Reference point with one of the portable units point for instance, measure the position exactness of the point in the segment 1 organize framework is to confirm the precision of the mistake model. The particular exploratory advances are as per the following:

①in Datum point estimated in tooling computerized model - The organize esteem;

②Use laser tracker to quantify various arrangements of reference focuses - The facilitate values at the birthplace on the three organize tomahawks, and afterward take the normal worth;

③Comparison benchmark - The deviation of the facilitate an incentive from the source of the real movement pivot in the advanced model, input the deviation incentive to the underlying feed estimation of the control framework;

④the spatial blunder that will be determined by the mistake model correct the remuneration to the underlying feed estimation of the control framework;

⑤Drive the portable unit to the hypothetical space position, utilize the laser tracker to gauge the repaid situating exactness, and confirm the rightness of the mistake model.

Table 2 Positioning reference point P Error compensation process table

Theoretical coordinates	Average coordinate value at origin	Initial feed value
$(1334.686, 847.886, 382.875)$	$(1284.371, 767.245, 382.343)$	$(50.315, 80.641, 0.532)$
in X Axis in motion P point at D_3 Middle coordinate	in Y Axis in motion P point at D_3 Middle coordinate	in Z Axis in motion P point at D_3 Middle coordinate
$(10.968, 647.563, 182.287)$	$(60.367, 343.631, 1.256)$	$(92.572, 23.021, 1.236)$
in X Axis in motion P Point line displacement error	in Y Axis in motion P Point line displacement error	in Z Axis in motion P Point line displacement error
$(0.061, 0.230, 0.131)$	$(0.045, 0.085, 0.023)$	$(0.012, 0.013, 0.022)$
P Point space composite error	Corrected feed value	Positioning error value
$(0.118, 0.328, 0.176)$	$(50.433, 94.092, 0.708)$	$(0.021, -0.032, -0.025)$

Positioning error $\Delta P = 0.046mm < 0.05mm$, Meet the positioning accuracy requirements.

To confirm the sanity of the tooling plan and accelerate the turn of events, an adaptable tooling test stage was set up. This section mostly finished the accompanying errands:

(1) Build an adaptable test stage, total the equipment association of the test stage, arrange the boundaries of the CNC framework, set up the connection between the engine and the coherent hub, and aggregate the PLC program to finish the control of the test stage.

(2) According to the development qualities of the portable unit of the test stage, a development blunder model of every hub was set up, the complete spatial mistake was determined, and the underlying feed esteem was revised and redressed, and the exactness esteem when the remuneration was estimated by the laser tracker to check the model rightness.

5 CONCLUSION

Consolidating with "very good quality CNC machine devices and fundamental assembling hardware", a significant logical and innovative undertaking "compound machining machine instruments for little and medium-sized airplane fuselage and enormous parts", in light of the fuselage assembly assignment of a particular kind of airplane, the structure attributes of the fuselage situating of the convergence opening of the segment cycle is the examination object, receiving the measured plan thought, joining the particular capacity and specialized record necessities, plan a bunch of flexible tooling framework, understand the flexibility of the situating of the fuselage outline crossing point opening, and defeat the center fuselage segment Challenges looked by assembly. The primary work did in the paper is as per the following:

(1) Completed the general plan of the flexible tooling framework. Taking into account the current advancement pattern of airplane flexible assembly tooling, joined with the field examination of Chengfei Company, we have perceived the real prerequisites of the assembly of the center fuselage segments, and explained the utilitarian necessities of the flexible tooling framework, consequently planning four diverse flexible tooling. The arrangement begins from the flexibility and receptiveness of the tooling, through the relative investigation of the favorable circumstances and burdens of each arrangement, joined with the item situating and holding impact test and mistake hypothetical computations, a structural tooling plan is chosen. Simultaneously, the general design and work process of the programmed boring and riveting framework and the work process of assembly the fuselage outline by the flexible tooling are presented.

(2) The itemized structure plan and strength check of the adaptable tooling framework have been finished. Beginning from the particular specialized boundaries and practical markers of the tooling, the measured plan idea is embraced to do itemized foundational layout of each piece of the adaptable tooling. Simultaneously, to help out the utilization of the tooling and the turntable, a ground helper gadget is planned. Also, the limited component programming ABAQUS is utilized to check the strength and inflexibility of the vital parts of the tooling, the unbending positioner and the gantry structure. The outcomes show that the tooling configuration meets the unbending nature and strength necessities.

(3) Completed the plan of the flexible tooling control framework. From the general viewpoint, the flexible tooling control framework was arranged, the framework equipment design was presented, 30 servo engines were numbered and the tooling control measure was set up, and the control innovation plan of single engine and multi-pivot coordination was proposed, and the tooling included the critical innovation of multi-channel is considered.

(4) The establishment and troubleshooting of the test stage have been finished. A flexible tooling test stage was fabricated, equipment investigating, boundary arrangement and program configuration were finished, the movement control of every servo hub was understood, the control plan of the servo framework was confirmed, and the situating blunder model of the test stage was set up and adjusted by the laser tracker. Tooling versatile unit, and completing exactness estimation tests, the outcomes show that the tooling situating precision meets the specialized markers.

5.1 Follow-up outlook

Later on, the assembly of fuselage segments in airplane will utilize more adaptable tooling innovation, and the size of the fuselage will differ more. Simultaneously, higher necessities will be put on the remaking time and flexibility of tooling. In spite of the fact that the skeleton assembly flexible tooling

framework planned in this paper completely meets the useful necessities and specialized markers, because of the restricted time, a few angles have not been included and should be improved in the subsequent examination, including:

(1) In the general plan of the flexible tooling framework, the emphasis is on improving its transparency and unbending nature, which diminishes the level of flexibility of the tooling. Simultaneously, the flexibility of the tooling is controlled consequently in two ways, and the other heading is changed physically influenced the remaking time.

(2) Tooling doesn't have a reasonable weight decrease standard to direct the lightweight plan measure. It primarily depends on experience and doesn't augment the weight decrease of tooling. Simultaneously, the limited component check of key parts is determined through streamlined model estimations. Regardless of whether the mathematical worth and the genuine match are not yet known.

(3) Although the current Huazhong control board can handle the development of every hub of the tooling and understand the tooling control work, the human-PC connection interface has not yet been created.

REFERENCES

1. An Xiaopeng. Industry 4.0: Why? What is it? How to look? China Information Technology, 2015, (2): 7-11.
2. Guo Hongjie. Development of Shen Fei's Digital Manufacturing. China Manufacturing Information, 2010, (16): 24-25.
3. Seven D. Pay attention to the new progress of aircraft digital flexible assembly technology. Aviation Manufacturing Technology, 2009, (18): 60-62.
4. Guo Hongjie. Flexible assembly technology for large aircraft. Aviation Manufacturing Technology, 2010, (18): 52-54.
5. Liu Hongwen. Mechanics of Materials I 5th Edition[M]. Beijing: Higher Education Press, 2010:185-187.
6. Henrik Kihlman, Magnus Engstrom. Flexapods-Flexible Tooling at SAAB for Building the NEURON Aircraft. SAE Paper, 2010-01-1871.
7. Branko S. Assembly Techniques for Space Vehicles. SAE Paper, 2000-01-3028.
8. John Hartmann, Chris Meeker, Mike Weller, et al. Determinate Assembly of Tooling Allows Concurrent Design of Airbus Wing and Major Assembly Fixtures. Society of Automotive Engineers Paper, 2004-01-2832.
9. John Hartmann, Chris Meeker, Alan Minshull, et al. Automated Wing Panel Assembly for the A340-600. Society of Automotive Engineers Paper, 2000-01-3015.
10. Peter Zieve, Todd Rudberg, Peter Vogeli, et al. A Two Tower Riveting Machine with a True Z AXIS. Society of Automotive Engineers Paper, 2004-01-2807.