

A Flexible Fixture for Aircraft Wing Assembly Based on a Parallel Kinematic Machine (Exechon)

2011-01-2555

Published
10/18/2011

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doi:[10.4271/2011-01-2555](https://doi.org/10.4271/2011-01-2555)

ABSTRACT

The parallel kinematics machine (PKM) Exechon is proposed to be used in a flexible fixture for aircraft wing assembly. The capability analysis and tests are required to investigate the suitability of the proposed fixturing solution. The research concern in this paper will be the static stiffness analysis of the Exechon device, which is a very important element of flexible fixturing solution for aircraft wing assembly using PKM. This paper will detail the experimental tests of the Exechon machine's stiffness to understand its stiffness characters and to provide validation data for Finite Element Analysis (FEA) work in developing analysis models of the Exechon device with representative stiffness characters. The preliminary FEA work in solid models and beam models with parametric modeling function will be included. Then the overall analyze loop and system deployment will be discussed with the proposed research framework of a flexible fixture based on Exechon technology for aircraft wing assembly.

INTRODUCTION

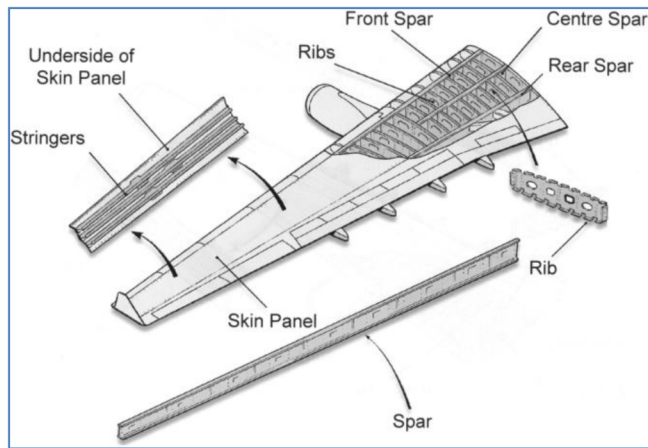
AIRCRAFT WING STRUCTURE AND ASSEMBLY PROCESS

The main part of an aircraft wing structure is the central wing box, which has four major product families: stringers, skin panels, spars and ribs (as shown in [Figure 1a](#)). From an assembly fixture point of view, the assembly process can be divided into three stages according to the complexity they cause for the assembly fixture system ([Figure 1b](#)) [1]. Generally the structural components in an aircraft wing have

varying sizes and relative low rigidity prior to assembly because of sheer sizes and materials used, and the assembly process requires high stiffness and tight tolerance. Traditionally rigid fixtures ([Figure 1c](#)) have been dedicatedly designed to meet these requirements in aircraft wing assembly while they need heavy investments in time for design and setting-up, and large initial cost. Moreover, these fixtures are large in size, expensive in cost and dedicated for one particular part family, which largely offsets their benefits when changes in components, processes and production volumes are frequently required from dynamic global markets. Therefore more flexible, adaptive and cost effective fixturing solutions are required for aircraft wing assembly automation while still keep the high performance in accuracy and stiffness.

PKMs FOR FLEXIBLE FIXTURE

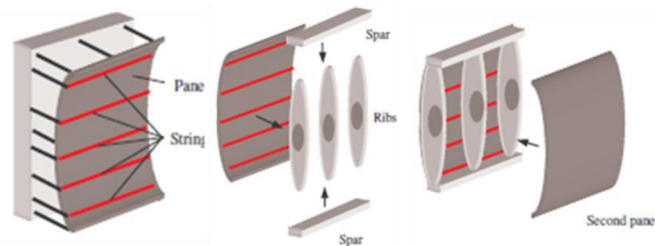
Recently robot-based systems have been developed for machining applications in the aerospace industry and they are capable of achieving the required tight tolerance and high automation with the aid of advanced control, metrology and calibration systems. Meanwhile, the parallel kinematics machines (PKMs) stand out from serial robots due to their better stiffnesses and flexibilities while maintaining the accuracy for aerospace applications. A novel PKM called Exechon has been selected here because it utilizes the flexibility and cost benefits of articulated arm robots, the performance of CNC machines, as well as the efficiency of special machines [3]. The structure of an Exechon machine and its kinematics model is detailed in [4, 5], while some improvements in design and calibration have been continuously made by the Exechon company for various



a) main components[1]



c) dedicated fixture[1]



S1: Stringers to panel S2: Ribs and spars S3: Panels to structure

b) main assembly stages [2]

Figure 1. A typical aircraft wing's

applications in machining, fastening and fixturing for large aircraft wings and fuselages [3].

Based on the aircraft wing box structure and assembly steps from the ALCAS project, the feasible assembly stage for flexible fixture application is identified and analyzed in details. Then a flexible fixture based on the PKM technology has been proposed for aircraft wing assembly automation since the system will be more agile, adaptable and sustainable compared to traditional dedicated fixturing solutions (shown in Figure 2). Currently PKMs have been analyzed and applied mainly for machining applications, which requires high accuracy and stiffness for relative short durations. But for fixturing applications, they require high tolerance and stiffness during long loading time as wing assembly process usually takes several weeks, so machine's structural stiffness needs to be analyzed and understood during the whole fixturing process before its implementation.

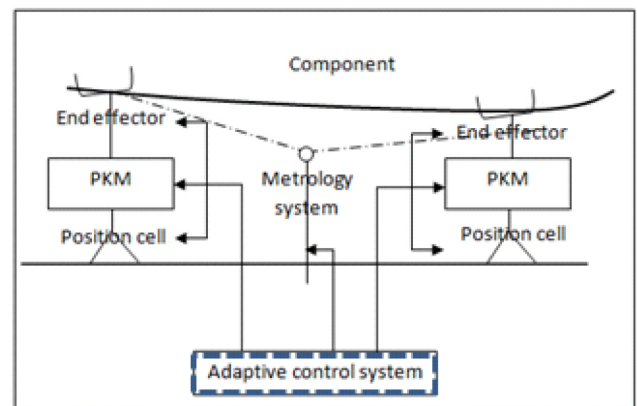
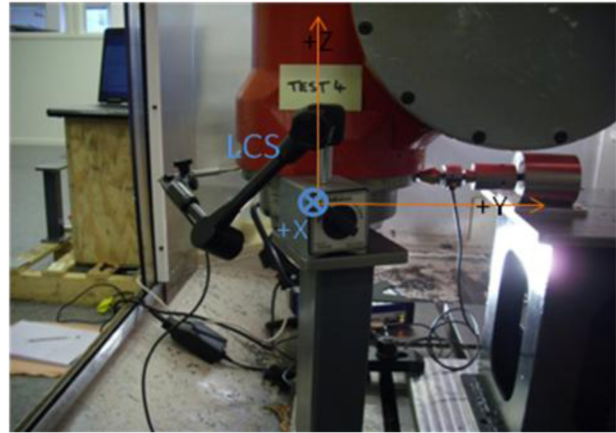
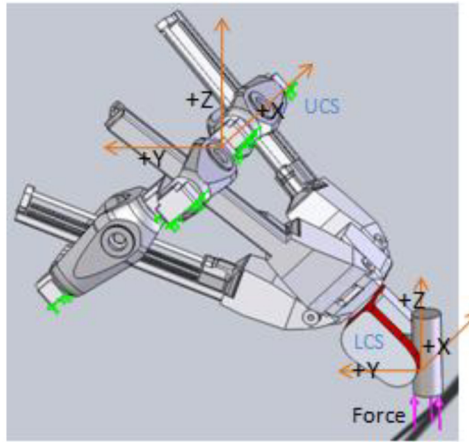


Figure 2. The proposed flexible fixture based on PKMs

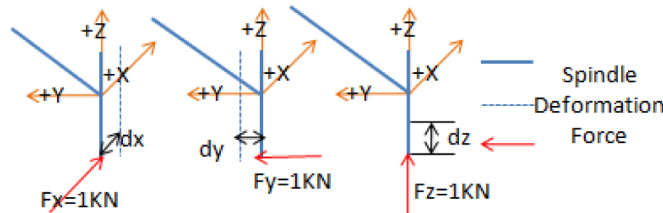
PAPER STRUCTURE

This paper will cover the experimental test of an Exechon's static stiffness to help to understand the source of deflections and the behavior of driving system under static loading condition and to provide validation data for Finite Element Analysis (FEA). Particularly the tests were undertaken to explore the directional stiffness of the Exechon machine at different positions, configurations and driving settings. As the Exechon was previously analyzed and applied for machining



a) A solid model of Exechon machine with LCS and UCS of [5]

b) The load and measurement units



c) Test sketches showing loads and deformations

Figure 3. The test cell in Exechon workshop

purpose, this will help to understand how stiffness varies in three axial directions and how the machine reacts to loads which are more typical for fixturing applications.

Preliminary FEA of the Exechon machine starts from the solid models of the machine used for design and manufacture. Having validated the solid Finite Element (FE) models' performances the developing process will continue to use idealised beam models with spring elements with a view to reducing the computational effort required to analyse a cluster of Exechon machines with different configurations functioning in a flexible fixturing during the assembly of aircraft wing structures. The analysis can be automatised through reconfiguring the platform's position, rebuilding the FE model and rerunning the analysis in parametric modelling in Patran.

Then the overall analysis loop will be discussed in the system deployment part, which includes the analyse, validate and execute functions. The overall research framework will be proposed to give a comprehensive fixturing solution with some further works.

EXPERIMENTAL TEST

The static stiffness of the Exechon machine is determined by the amount of deflection that the machine exhibits for a given amount of force in a known direction. The purpose of this work is to physically test the machine in a laboratory environment in order to quantify the directional stiffness of

the tripod arrangement to provide experimental data for validating FE models simulating equivalent test conditions of PKM. This is relevant to all applications of PKM technology in manufacturing but is particularly important for fixturing applications as the structural stiffness of a PKM under typical loading conditions will be the main concern for achieving tight assembly tolerances in aerospace.

TEST METHOD

The method used for this static loading test is applying a known load to a position in each of the three axial directions in the Local Coordinate System (LCS) followed by the measurement of the deflection induced in the direction of the applied load (Figure 3). Special test conditions will set to examine effects of some factors on test results; these include static loading in three axial directions at various positions, static loading in the vertical direction Z for long durations (maximum 30 minutes) and loading at different positions on wrist house.

TEST PROCEDURE AND EQUIPMENT

The experimental procedure is firstly to set up a rigid fixture with the load cell attached (a in Figure 4a). The load sensor is a U9B manufactured by HBM, and is capable of 10kN of force (b in Figure 4a). The Exechon is driven up until it comes into contact with the load sensor, and its position is recorded from the machine's control unit. Load is applied in line with the axes of LCS (shown in Figure 3a) with the

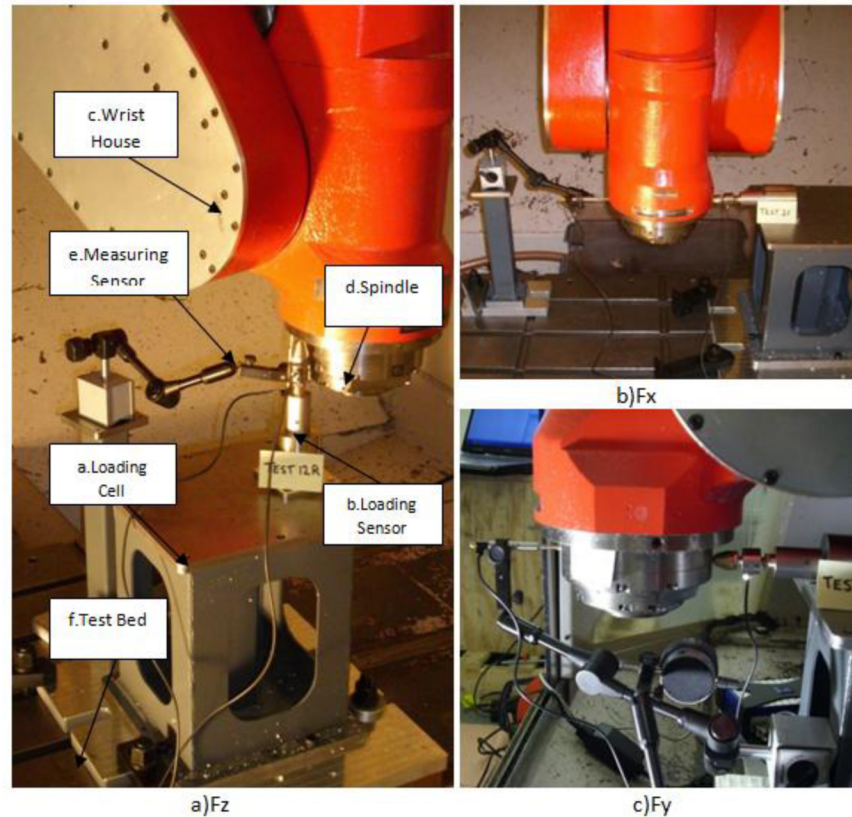


Figure 4. The Exechon machine and test devices

measuring probe (e in Figure 4a) mounted nearby for vertical direction Z (Figure 4a) or directly opposite for horizontal directions X and Y (Figure 4b and 4c). The probe is connected to a HBM Spider8 signal amplifier which feeds into a laptop. HBM Catman data logging software is then configured to transform the signal into a displacement. When set the laptop begins recording data, the load cell will be manually activated. When 1kN is reached, recording stops, the load cell and fixture is moved to a different position ready to begin the process again. The measuring devices have been calibrated before the test and the data flows among test devices as shown in the flow diagram (Figure 5).

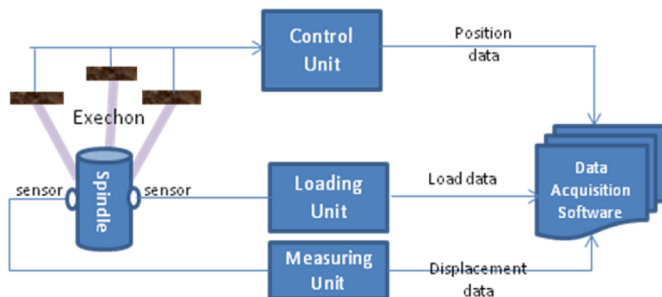


Figure 5. Data flows among test devices

TEST RESULTS AND DISCUSSIONS

Learned from previous tests experience, a new loading cell was designed with improved structure and stiffness to reduce slips and deflections [6]. Furthermore some specific test conditions mentioned in test method section were considered in the new static loading tests, and the results for different test positions and conditions are presented in this section. The driving system is working at Drive ON setting, while at Drive OFF setting it is switched off and the braking system is activated to lock the machine in position.

1) Loading at various positions: The displacements under 1kN loading in X, Y and Z directions can be listed and summarized in Table 1 for two loading conditions. The loading positions relating to Universal Coordinate System (UCS) and results for Drive ON setting are plotted in Figure 6, in which each color represents loading and resultant displacements in one axial direction. The lines' lengths represent the scales of resultant displacements in those directions (100mm length represents 0.05mm displacement).