Self-Adapting Parallel Kinematic Machines

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ABSTRACT

Historically, assembly of large aerospace structures has always required large, heavy duty, expensive machines designed and built with (and for) high accuracy over the entire work envelope. Such large machines are also generally very complex and it is normally financially and physically impossible to build these machines with more than one spindle/assembly tool.

The presentation will present "use cases" utilizing a platformless design, to deliver high dynamics and accuracy while dramatically reducing cost and eliminating the restrictions of one spindle/assembly tool. Case studies will show the application of extreme mobility in combination with adapting technologies such as cross lasers, which can perform accurate agile assembly over very large areas without the use of accurate large expensive heavy duty structures. Additional discussions will address case-studies on the ability to use small agile modules that can perform

The Parallel Kinematic Machines (PKM) developed since 1985 by Karl-Erik Neumann, starting with the Tricept 600, continuing with the Tricept 605, 805, and 9000, and the new "balljointless" Exechon X300, X700, and X1100, ending up in the latest "platformless" XT300S, XT700S, and XT1100S, has always been striving to give aerospace manufacturer a solution that utilize the flexibility and cost benefits of articulated arm robots, the performance of CNC machines, as well as the efficiency of special machines.

Exechon was founded around this dream in 2004, and the first "balljointless" X700 machine saw daylight summer 2006, and since then the technology has been licensed out to twenty one (21) Manufacturer and Integrators worldwide.

PLATFORMLESS PKM MACHINES

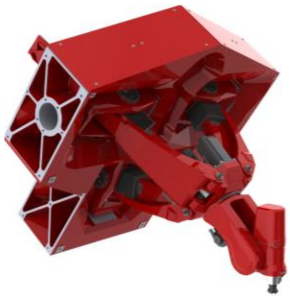
In 2006 the Exechon technology revolutionized the PKM technology by eliminating the ball joints that were mandatory in all previous PKM machines, and it was now time to take the technology one huge step further to prove it to be a general worldwide used technology within Aerospace and Automotive.

The way to achieve this goal was to eliminate the last remaining obstacle; the always present heavy platforms or structures holding and supporting the legs and/or actuators of all existing PKM machines.

Going from the first X700 to the X700S machine, the moving mass was reduced by 40% (300kg) by simply moving the motors for axis one to three from the moving lower platform to the neutral inner gimbals, and to further improve the dynamics and temperature stability, the motors for axis four and five was put on the outside instead of being build in.

However, to accomplish true "Self Adapting Parallel Kinematic Machines for Large Wing and Fuselage Assembly", reducing the moving mass was not the only solution.

To reduce the cost, simplify the design, and make it possible to utilize multiple hole drilling, it was also necessary to substantially reduce the weight of the PKM module to allow it to be mobile within a low cost system.



A big remaining problem(until now) in the PKM technology has been the fact that all legs and actuators have to be mounted in some kind of platform or structure allowing it to resist the forces from each legs individually and in combination, resulting in a very heavy design preventing it from being agile and mobile.

Finally, after almost thirty years since the first PKM machines saw daylight, Exechon has developed a PKM machine that can maintain, or even increase, its stiffness and accuracy by totally eliminating the previous mandatory platforms and structures supporting the legs and actuators.

Exechon has solved this problem by connecting the outer gimbles of actuator one and three, eliminating the need of central support of these gimbles and at the same time making it possible to add on extra material in the centre, which was impossible in the platform design due to cable issues, resulting in increased stiffness.

This integrated one and three gimble also prevent actuator one and three from twisting in relation to each other (when a side force is applied) on the machine, resulting in increased stiffness and improved accuracy.

Further the outer gimble of actuator two has been turned ninety degrees eliminating a centre support for actuator two as well. This turned design also puts the holding points of actuator two right on top of the side structure, resulting in increased stiffness.

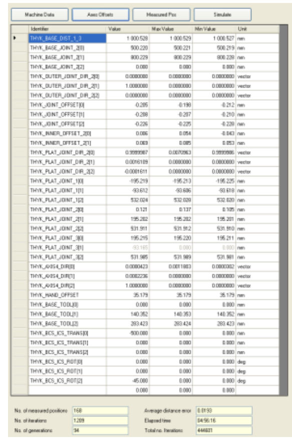
Overall the above patented design reduces the mass of a XT700S module with 3000kg, making it very suitable for “Self Adapting Parallel Kinematic Machines for Large Wing and Fuselage Assembly”.

CALIBRATION

To really make “Self Adapting Parallel Kinematic Machines for Large Wing and Fuselage Assembly” in combination with multiple hole drilling practical, it is crucial to find a way to calibrate the machines without using expensive and high tech equipment such as Laser Trackers and computerized adaptive systems.

Far more important is also the possibility to calibrate the machine tool vector, and not only the tool centre point, whish is a serious problem in most existing calibration systems.

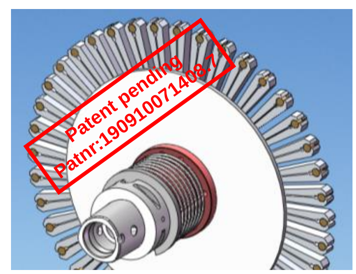
Exechon has developed a system using a FARO Arm for automatic calibration. The machine is programmed in a pattern, letting the machine move to a number of points and repeats this pattern and points in multiple different tool vectors. The pattern can be adapted to an existing jig or fixture to avoid disassembly of any parts in the system during calibration.



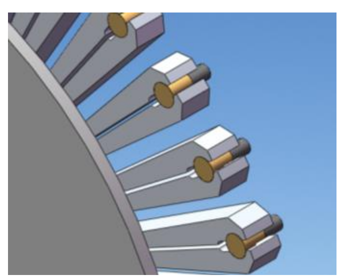
After collecting a selected number of x, y, z, and vector values, the values will be uploaded onto an external internet based calculation computer, which performs a massive amount of mathematical parameter calculations offline, and after 30 minutes a complete set of thirty-one (31) machine parameters and five (5) reference positions are ready to be downloaded and implemented into the machine, fully automated, resulting in a volumetric accuracy of around +/- 10 microns.

SIMPLIFIED ASSEMBLY

Another necessary item in “Self Adapting Parallel Kinematic Machines for Large Wing and Fuselage Assembly” is of course the assembly process itself. As earlier discussed, conventional assembly systems are far too complex and way too expensive to use in multiple hole drilling and assembly operations.

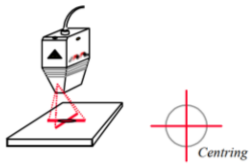


For this purpose Exechon has in cooperation with one of our Licensees developed a new simplified method to assembly fasteners in the new China Big Plane, using fastener “discs” that are loaded off-line, where jamming of feeders and other related problems doesn't effect the production nor the quality of the automated assembly.

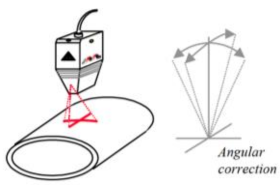


The discs are actually to be considered as tools, and are consequentially equipped with tool holders, and these disc tools are loaded into the tool magazine, either manually or automatically, and being seen as tools by the machine and its program, the assembly process is for sure simplified and guarantees a high up-time.

CROSS LASER

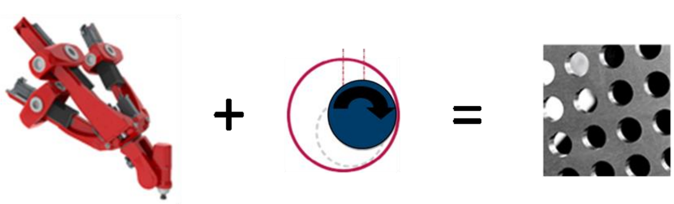


It has been a long lasting problem how to adapt multiple assembly heads to a unknown aero plane surface such as a wing panel or fuselage without using time consuming probing etc. To overcome this problem a new type of probing system was developed in cooperation with Boeing and Meta UK, a system combining two linear lasers into one laser head, a so called Cross Laser. The Cross Laser sends four points of measurements to the system which in its turn in a few seconds can calculate the accurate surface angle and position as well as hole and edge positions within 50 micron.



ORBITAL DRILLING

Some of the holes required to be drilled during assembly cannot be drilled conventional due to the risk of dilamination, which is an absolute no-no in automatic assembly, and so far the only good method to avoid this has been to use additional Orbital Drilling heads that further add on complexity, weight and cost to allready complex, hevy and costly systems. However, since just a few month back it is now possible to incorporate the Orbital Drilling process from Novator into the Exechon technology and achieve Orbital Drilling hole accuracy down to H6 without any additional mechanial equipment but just using the circual imterpolating capabillity of the Exechon technology.



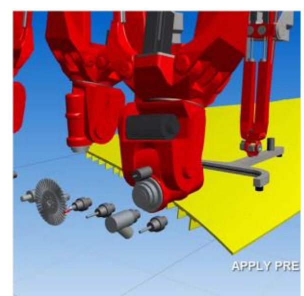
SELF ADAPTING PARALLEL KINEMATIC MACHINES FOR LARGE WING ASSEMBLY #1

Drilling multiple holes and assembly of multiple fasteners has become a nightmare requirement since more and more planes have to be manufactured in a shorter time.

The solution promoted by Airbus is “Multiple Hole Drilling & Assembly” which as earlier described is both technically and financially impossible with today’s large single head machines.

Exechon is currently participating in developing such a “Multiple Hole Drilling & Assembly” machine in cooperation with Airbus UK and the Manufacturing Technology Centre (MTC) in UK.

The system with consist of three parallel gantry mounted XT305S machines with 500mm stroke and traditional spindles with tool changers, and it will utilize all technologies earlier mentioned in this paper as well as a state of the art fixturing system developed by other parties within the project.



The process will be as following;

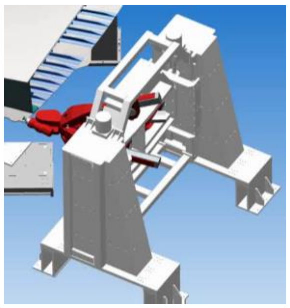
1. Positioning the gantry over the wing
2. The XT305S machines locate the surface and references using a permanently mounted cross laser.
3. The XT305S machines picks up selected tools from the tool changers.
4. The XT305S machines simultaneous drill and counter-sink all holes within their reach.
5. The XT305S machines also simultaneous perform Orbital Drilling of all holes requiring this type of operation within their reach.
6. The XT305S machines picks up vacuum cleaners from the tool changer and cleans all holes.
7. The XT305S machines picks up fastener disc and seals all holes.

8. The XT305S machines assemble all fasteners

9. Move the gantry to next position

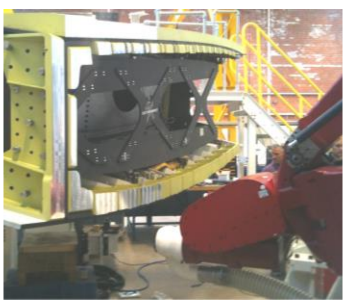
SELF ADAPTING PARALLEL KINEMATIC MACHINES FOR LARGE WING ASSEMBLY #2.

For years discussions has been going on within the aerospace industry around mobile machine tools, and the Exechon technology has for the first time made it possible to utilize such a system.



The system is designed and built in cooperation between Airbus UK, Queens University, and Güdel, both Exechon Licensees. The system is based on an Exechon module from Hwacheon, a Licensee in Korea, a structure with a z-travel from Güdel, and an Omni Move from Kuka Automation, and the system is designed to machine the root end in multiple jigs at Airbus.

The system has currently been verified at Airbus UK with exceptional results such as machining accuracy in one Exechon position of 20 microns and machining accuracies over the whole 4,5 meter root end of 40 microns.



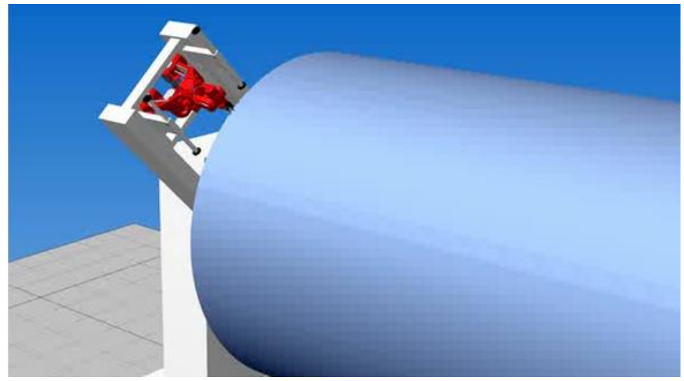
SELF ADAPTING PARALLEL KINEMATIC MACHINES FOR LARGE FUSELAGE ASSEMBLY #1

A new problem has occurred in assembly of aero plane structures due to the fact that fuselages are mainly manufactured in composite, which is very stiff and inflexible.

The problem is that it is virtually impossible to manufacture fuselages with a diameter of e.g. 6,5 meter, accurate enough to be able to mount two of them together end to end due to variations in diameter and ovality.

To solve this problem the ends of the fuselages have to be machined, and to build a traditional machine performing this task will require a huge structure with high accuracy and accompanied price tag.

Using a small light XT300S with a cross laser for self adapting capability, mounted in a non accurate structure, that in its turn is mounted on a high accuracy standard “Fibro” turn table, adapting its coordinate system to an average best fit of the fuselage, allows not only a low cost design, but also a optimized material removal that guarantee a minimum of material removal from the fuselage maintaining the structure integrity.

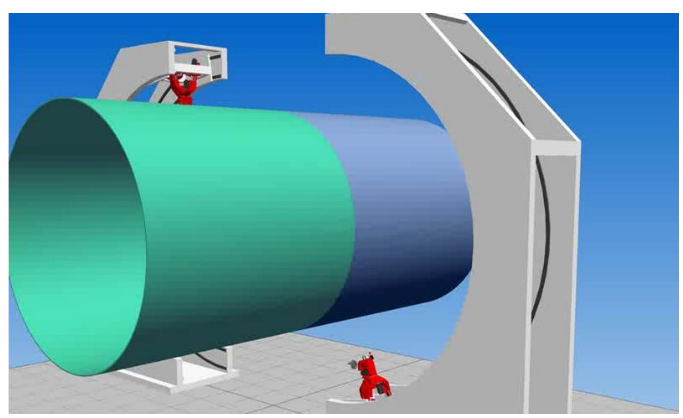


SELF ADAPTING PARALLEL KINEMATIC MACHINES FOR LARGE FUSELAGE ASSEMBLY #2

The next step in the process, mounting two fuselages together, normally require a huge machine structure with a very complex and heavy drilling and assembly head that can move around the fuselage joint with high accuracy.

Such machine, and especially the head, tends to become very complex with multiple integrated CNC functions like a drilling head, a sealing head, cleaning functions, and fastener assembly heads with multiple feeders, that all are normally associated with low uptime and a high price tag.

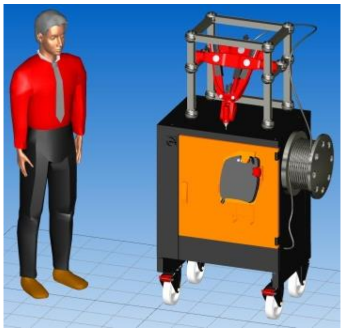
Instead we propose utilizing two small light XT300S using cross lasers for self adapting capability, mounted in a non accurate structure.



The process will be as following;

1. Positioning the two XT300S machines around the fuselage.
2. The XT300S machines locate the surface and references using a permanently mounted cross laser.
3. The XT300S machines picks up selected tools from the tool changer.
4. The XT300S machines perform simultaneous drilling and counter sinking all holes within the reach of the XT300S machines.
5. The XT300S machines also simultaneous perform Orbital Drilling of all holes requiring this type of operation within their reach.
6. The XT300S machines picks up vacuum cleaners from the tool changer and cleans all holes.
7. The XT300S machines picks up a fastener disc and seals all holes
8. The XT300S machines assemble all fasteners
9. Move the XT300S machines to next position

PORTABLE DRILLING & ASSEMBLY AUTOMATION



The future Exechon XMINI is a potable "machine tool robotics system" combining the flexibility and dynamics of articular arm robots with the accuracy and stiffness of CNC machines. This new patented light design gives these modules extreme mobility and, in combination with adapting technologies such as cross lasers and force sensors, it can perform accurate agile operations over very large areas without the use of accurate large expensive heavy duty structures.

The portable XMINI it's a new way of thinking but it's also easy to imagine the use of two to four XMINI machines in every wing and fuselage structure made for ever plane in the world ending up in hundreds of machines needed worldwide every year.

This small version of the Exechon PKM Systems is currently on an initial concept development stage with key users in the aerospace industry such as Airbus and Boeing. The concept is to develop a small in size and light weight PKM system that would be easy to position around aerospace parts that require complicated manufacturing processes that up to now require an extensive and expensive deployment of specialized jigs and fixtures that usually are used for the specific task without the ability of reuse or redeployment on other parts of a manufacturing line. For this reason the majority of these manufacturing processes are today 100% manual.

The Exechon Mini will be designed in such a way so that is light-weight but robust and accurate. The initial design specifies a mix of aluminium and composite (enhanced carbon fiber) parts, together with innovative support fixtures.

The XMINI will revolutionize a large number of existing manufacturing processes and will allow manufacturers to change custom made tooling manufacturing to flexible processes.

Procedures such like drilling and riveting of complex structures will be simplified with a use of a number of XMINI's that can be moved from one manufacturing station to another depending on volume and they will not be part specific.

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