The dimensional and geometric compensation for Cartesian robots and machine tools is becoming a manufacturing engineering tool and the volumetric diagonal measurement is confirmed a modern instrument for the preventive maintenance. The laser Doppler make this change-up possible.

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Abstract

In the actual world competition it is always requested the design and the manufacturing of complex machines for the automatic manufacturing of object, also of complex type, as the aircraft body. Are always requested more sophisticated equipments, more accurate, higher speed of actuation , but always less expensive. The massive mechanics and accurate have always been the prerequisite for the satisfaction of the accuracy to the detriment of the cost and the dynamic performances. With the progress of the power of calculation for the CNC is now possible to generate the errors model and compensate it with opposite movements. The theoretical limit of this technique is the mechanics repeatability, but the practical limit is in the difficulty to measure all the errors in an economical reasonable time. By the Optodyne laser Doppler it is possible to measure the error parameters much more rapidly and make the electronic error correction possible and profitable, including the angular deformation of the cross beams . The results of correction of a large dimensional robot (working volume 780 cubic meter), measured by the Optodyne laser Doppler and corrected, in all the working area with matricial and vectorial techniques by means of 52 compensation tables, are reported in this article.
The residual error, measured with the volumetric diagonal technique meeting the new ISO 230-6 or the well established ASME B5-54 standards, is less than the dimensional variation due to thermal expansion. The dimension of the diagonals (fast to be measured) will be used as stability reference for the determination of eventual maintenance actions.

Introduction

The automated manufacturing machines, in this case the CNC machine tools and the Cartesian robots, but also all the CMM measuring machines have to be both Accurate and Fast but also and especially Cost effective. The cost for the manufacture of complex production tooling is transformed in increased repeatability better productivity with consequent better yield in constant higher quality level. The quality is a saving tool, because are reduced the cost at the downstream of the production process including maintenance and safety. The feed is related to the inertia reduction, and thereafter of the weight reduction. The new composite materials, ceramics, aluminum alloys and titanium can solve the weight problem but often are too expensive and not enough robust for practical application in the manufacturing industry. For the manufacture of large machines the steel alloys in welded structures is normally used in order to increase the inertia momentum and reduce the weight .

The construction of accurate machines with orthogonal axes is based on the capability of manufacturing and installation of structures and guide-way, that in spite of the gravity force, have to be perfectly straight and orthogonal between themes. Alternatively to the absolute accuracy of the mechanical structures are becoming popular alternative methods based on the electronics and servo systems. Is the way to cancel electronically the error produced by the mechanics providing new positioning data, that pushes the machine in the correct position. The electronic compensation by error tables is commonly used by the CMM manufactures that in this way have overcame the compromise between accuracy and massive construction. On the CMM, with the support of powerful electronic processor are compensated up to 21 errors obtaining accuracy of few micrometers on machines of large dimensions, too. This technique is experienced by several years and now, with the capability of new numerical controllers that contains the possibility of the utilization of multi axis electronic compensation, synchronized and conditioned. Synchronized is a compensation that is applied in a direction different by the axis movement of the axis that is moving, used for instance for the compensation of the vertical or horizontal straightness compensation. Conditioned is a compensation where the comp value depends both by the position of the axes that is under compensation and by the position of the other axis. For instance in the positioning of an horizontal axes on top of which is mounted a further axes, the positioning error depends both by the position of the horizontal X axes and by the vertical Z axes by this formulae

$$Ep(x,z)= E(x) + \theta (x) * Z \qquad (1)$$

Where:
Ep(x,z) is the positioning error in x direction at the at the tool position
E(x) is the positioning error in x direction measured close the X guideway
θ (x) is the angular error (Pitch) of the X at position (x) expressed in radian
Z is the distance between the tool point and the guideway (Abbe offset)

Is consequent that, if the error due to the angular deviation [θ (x) * Z] is appreciable, in respect to the basic linear positioning error [E(x)], one compensation table for the X axes would be not enough for the compensation of all the point of the working area.

Some of the CNC for machine tools allow the use of more than one table for each axes, allowing the tables to sum or multiply between them in order to generate appropriated compensation in all the points of the working area. The theoretical limit of the compensation accuracy is the machine repeatability but the practical limit till now, has been the possibility to obtain accurate data errors in a reasonable economical time. Having the capability for measure, compensate and check in short time the compensation process become economically competitive with the manufacturing process and can be integrated in it. During manufacturing process and machine erection the errors are taken under control and corrected. The reduction of dimensional and geometrical errors during the manufacturing process takes time and is exponential proportion to the accuracy result to be achieved. The optimal compromise is to manufacture in accurate way, but to leave at the electronic compensation the task to fill the gap for reaching the final accuracy requested by the contractual specification. The measuring instrument line that include both accuracy and measuring rapidity is demonstrate to be the laser Doppler interferometer LDDM (Laser Doppler Displacement Meter) produced by Optodyne.

a practical case , ALENIA S.A.F.A. project in Nola (Naples)

The manufacturing of large dimension fuselage for new generation airplane, as for instance the new generation 700 seat airplane A380 produced by the European consortium AERBUS, needs automatic product lines in order to reduce the manufacturing processes time. The lines have to be also accurate because the various part assembled at the final assembling are coming from various plants in Europe.

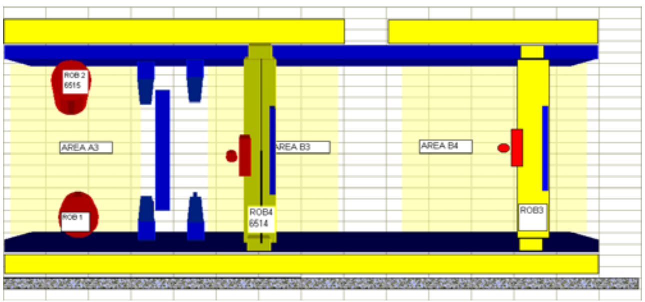


Fig1 :

SAFA robots Alenia NOLA
Top view
dimensions 50m x10m x 9m high

The large dimensional Cartesian robot is produced by Bisiach &Carrù of Turin, 50m(15ft) long 9m(27ft) high includes 4 operative independent units, two vertical and two portal, every unit has a working head with 3 rotary axes. The line is composed by precasted elements and by a structure welded manufactured directly in the local site. Inside this structure are located 3 working areas where are placed the fuselage parts to be worked, transported by giant carriages with accurate calibrate supports. For this machine was decided to use extensively the electronic compensation of the structural deformation in order to make the machine accurate and keep it accurate even the case of inevitable assessment of the ground and the foundations. The measure of the residual errors is performed by the volumetric diagonal (UNI-ISO 230-6 and ASME B5-54) that makes possible the rapid monitoring of the machine conditions allowing the preventive maintenance possible.

Software compensation tools

The axes of each of the 4 actuators are controlled by Siemens 840D CNC that allows to interact on the theoretical positions in the work part program derived by a CAD/CAM with many different options. On each of the singular CNC are used the following compensation tools:

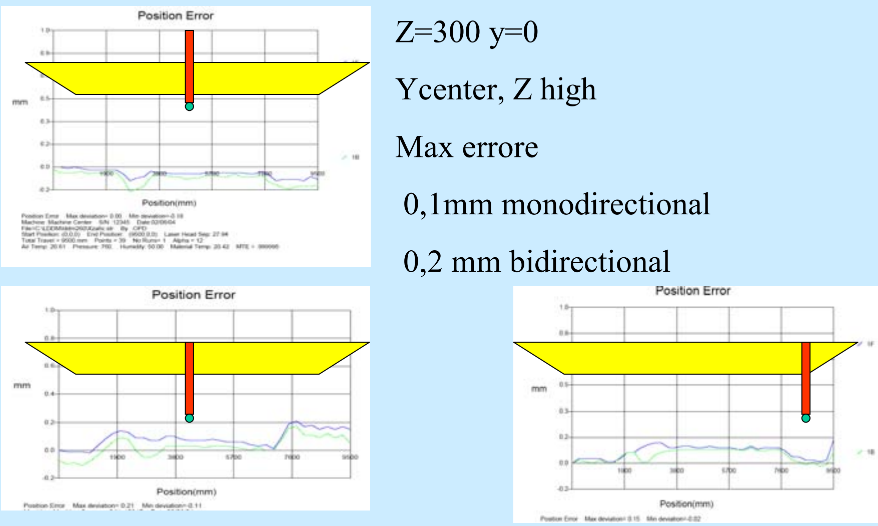
N° 2   Scale factor compensation (to uniforming the gantry axes X1,X2)
N° 3   Pitch error compensation (to synchronize the gantry axes X1,X2 and roughhew the Y axis)
N° 5   Reversal error compensation for backlash (X1,X2, Y, Z)
N° 52   Cross compensation tables with concatenation up to 3 levels (i.e. X function of Z position and Y position)
Totally was used more than 1800 compensation points

Compensation Strategy

Due to the large dimension of the machine and the large errors at the beginning was implemented a structured procedure by several compensation layers, have been gradually measured the errors for the singular degree of freedom in several position of the space of the working volume, compensated and measured for verification. At the end as final verification has been done the measurement of the positioning errors on the diagonals of the working volume.

Tablle 1: Errors individually measured before and After the compensation (Robot R4 sector B3)

Type of error	**Axes**	**Position of measurement**	**Before compensation**	**After compensation**	**Improvement**
Vertical straightness	X1	0- 10 m	0,65 mm on the guide	0,25 mm tool point	**260 %**
Horizontal straightness	X1	0 - 25m	1,75mm on the guide	0,1mm (0-10m) tool point	**1750 %**
Positioning	X	Tool point Z =300 Y = 0 (center Y travel , Z low)	0,71 mm	0,1 mm	**710 %**
Positioning	X	Tool point Z =1400 Y = 0 (center Y travel, Z low)	1,57 mm	0,2mm	**875 %**
Positioning	X	Tool point Z=1400 Y=2500 (lateral Ytravel, Z low)	-	0,2 mm	-



Position error in 3 different position AFTER compensation 0,2 mm

FIG.2:
Residual positioning error along the X axes in 3 different position of the working area . On each error plot is sketched the cross beam and the vertical axis Z with at the end the tool. Is noted that the positioning errors, due to the angular errors, that before the compensation was producing errors up to 1,57mm with differences of 0,9 mm are now reduced to 0,2 mm with differences of 0,1mm making the errors in the working area little and uniform.

Results verification of the compensation and volumetric diagonal measurements.

The measurement of each singular error is very complex and time consuming, alternatively can be measured the accuracy of positioning along the diagonals of the machine body that is recommended by the international standards such ISO 230-6 ed ASME B5.54 for a fast evaluation of the volumetric accuracy. It can be done because the diagonal measurement is sensible to all the error components. The test of accuracy along the diagonals, par ASMBE B5-54 standard have been used for several year at ***Boeing Aircraft*** and by several other manufacturers for the determination of the volumetric positioning accuracy.
Besides the data of volumetric accuracy can be used as a master fingerprint for the preventive maintenance. In this specific case the time for the measurement of four 10m diagonals was less than 4 hours. The error measured on the diagonal is larger than each singular error, it can be considered as the root main square of the 12 singular basic errors. Assuming the errors have the same amplitude, is good approximation consider the tolerance on accuracy on the diagonal 3,45 (root main square of 12) larger than the tolerance for each singular axis.

Fig. 3: Diagonal measurement results

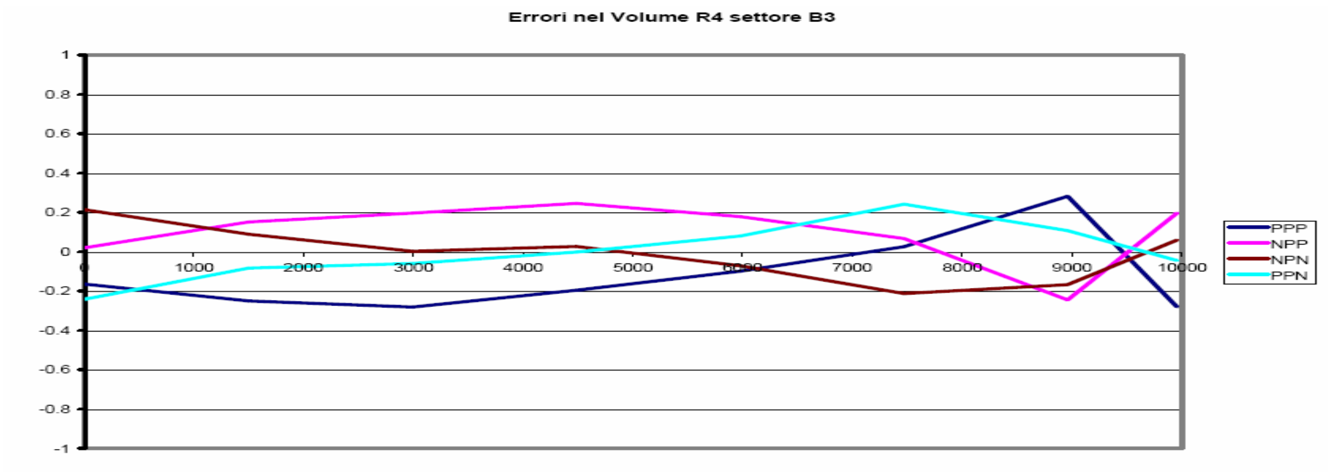


Fig. 4 : Measurement of diagonal volumetric positioning on Portal R4

Measuring Instrument Used:

Optodyne -MCV 500 Compact Linear Measuring System, single beam and single aperture.
Optodyne -MCV 4000 Dual Beam Laser Calibration System that include Quad detector and Pentaprism for the measurement of Rectitude and Squareness.

Conclusion

Have been used new electronic methods for supporting mechanics, in order to reach the target of positioning the tool tip where necessary for machining with the requested accuracy. In order to have an absolute term of comparison for the estimation of the reached accuracy have been used the temperature. The reached accuracy of +/- 0,2 mm on 10 meter, the dimension of the working piece, is equivalent at thermal expansion for 4 °C , considered not influent for the production process. The accuracy of the machine measured on the diagonals in less than 4 hour for each working area is kept as indication of the condition of the machine (from the point of view of the efficiency of the mechanical structure and the servosystem) in order to be repeated cyclically in order to program an eventual maintenance before wrong part are produced. The results was made possible because of the good repeatability of positioning of the machine, the versatility of the CNC and for the USABYLITY and accuracy of the measuring system utilized.

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