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(54) **CNC machine for cutting with plasma, oxy-fuel, and water jet, capable of direct or additional bevel cutting, using autocalibration for self-adjustment, and the method of its adjustment by autocalibration**

(57) The presented invention relates to the CNC machine for cutting with plasma, oxy-fuel, and water jet used as a cutting tool, being capable of direct and additional bevel cutting of pre-cut workpieces, using autocalibration for self-adjustment, consisting of lateral sides (1) of the machine, provided with **X** motion axes; a gantry (2) provided with drives (5), **Y** motion axes for motion of a support (3), and the support (3) provided with a drive (6), **Z** motion axes for motion of cutting heads (15), and the cutting head (15) being able to move rotary along **A**, **B** motion axes by drives (8, 9) and carrying a cutting tool (10); a cutting tool position calibration station (11); a control system (16) with interpolator; a working table (12); wherein the support (3) is provided with the workpiece position calibration station (4) connected with a laser line scanner (14) provided with the drive (13) for its rotary motion along the **C** motion axis, the cutting tool position calibration station (11) is located in the intersection of working areas of the cutting head (15) and the workpiece position calibration station (4), and the output of the cutting tool position calibration station (11) and output of the workpiece position calibration station (4) are connected to the inputs of the control system with interpolator (16) coupled through its input with the drives (5), (6), (7), (13) of **X**, **Y**, **Z**, **C** motion axes of the machine. This invention also relates to self-adjustment of the CNC machine by autocalibration.

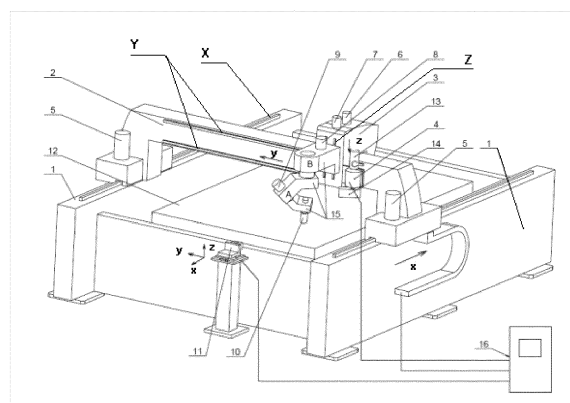


Fig. 1

Description

Field of the invention

[0001] The present invention relates to the CNC machines for cutting with plasma, oxy-fuel, and water jet designed for the bevel cutting of workpieces, necessary for the following welding processes as well as for other applications in machinery, metal industry and a wide range of manufacturing processes, where these cutting technologies can be applied. The invention also relates to the method of adjustment of such machines by auto-calibration.

Background of the invention

[0002] One of important tasks of cutting machines in industry is to cut workpieces with complicated welding surfaces - that means to cut workpieces with bevels that are necessary for following welding processes. The bevelled edges can be of V, Y, X, and K shapes. Plasma, oxy-fuel, and water jet cutting technologies allow to cut workpieces only within limited thickness ranges that are determined by effective lengths of an energy beam produced by the corresponding technology of given power. In the bevel cutting the maximum thickness is reduced even more depending on the bevel angle, i.e. the tilting angle of a cutting head with respect to a vertical to a surface of a material being cut. Another problem is that the cutting tool cannot not perform multiple passes along the cut edge because it could damage the edge created by preceding cutting process. That refers particularly to the cutting of Y, X, and K shape bevels using oxy-fuel jet cutting.

[0003] Currently produced CNC machines using plasma, oxy-fuel, and water jet cutting technologies are therefore used for bevel cutting of only workpieces from the material having thickness smaller than allowed by the corresponding technology in straight cutting. Workpieces with material thickness exceeding permitted range for straight cutting are consequently bevelled mechanically or using other methods, for example using oxy-fuel jet carried out at special bevelling machine systems manually or using different degrees of process automation. Due to this, the manufacturing process becomes time-consuming and not very effective.

Summary of the invention

[0004] The said shortcomings can be eliminated with the CNC machine according to the invention that is characterised by the following composition including:

- working table;
- lateral sides provided with longitudinal guideways - **X** motion axes;
- gantry with a drive for its motion along **X** motion axis, provided with **Y** motion axes intended for moving the

support carrying **Z** motion axes and a drive system providing motion of a cutting head along **Z** motion axis, and carrying the cutting head equipped with a motion system providing tilting motion of a cutting tool in **A**, **B** directions, connected to the workpiece position calibration station and a laser scanner pivotable by 360 degrees around its axis (in the attached figures referred to as **C** direction);

- cutting tool end point position calibration station located in the working area of the cutting head of the machine, and the workpiece position calibration station that enables to measure an actual position of the cutting tool end point in direction of **x**, **y**, **z** coordinate axes of the cutting machine;
- control system with interpolator, wherein the outputs of the cutting tool end point position calibration station and the workpiece position calibration station are connected to the control system. Working areas of the cutting head and the workpiece position calibration station are defined by their motion ranges.

[0005] In addition to direct bevel cutting of workpieces with bevels of defined angle within the thickness range determined by effective lengths of energy beams of corresponding cutting technology, the CNC machine according to the invention provides also additional cutting of bevels of workpieces that have been straight cut in advance within the range between their given thickness and the maximum thickness that provided technology is capable to cut. High accuracy of cut workpieces is achieved by the autocalibration system of the machine that eliminates a need of precise and time consuming mechanical adjustment of the machine by an operator.

[0006] In the mode of direct bevel cutting of workpieces, the machine works in a standard way, i.e. workpieces are cut out from a full sheet of a material according to the cutting program, wherein the program controls the motion of the cutting tool along the edge being cut once, twice, or three times depending on the required shape of the bevelled edge. One pass is required for straight cut and V shape cut; two passes are needed for Y and X shape cuts; and three passes are needed for K shape cuts. In each respective cut it is necessary to change the angle of the cutting tool setting with respect to the surface of the material and offset the end point of the cutting tool relative to the contour being cut so that the final shape of the edge of the workpiece corresponds to the required shape.

[0007] In the mode of additional bevel cutting the workpiece is first cut out using straight cutting and then an operator places the cut workpiece into a free area of the cutting machine and then navigates the support of the cutting tool with the workpiece position calibration station over such relocated workpiece. Then using the control system of the machine the operator starts the identification process of the workpiece position. Within this process the calibration station measures the precise position

of the cut workpiece and the control system automatically calculates the rotation angle of the cutting program as well as a new position of starting point of the cutting program so that the cutting program is synchronized with the relocated workpiece. When this operation is completed, the operator resumes the cutting process, wherein in this phase only bevelled parts are cut on edges of the cut workpiece. When a Y shape is cut, after cutting the edge the process is completed. If X and K shapes are to be created, after cutting the upper edge the workpiece is turned upside-down by the operator so that the lower surface of the workpiece comes upside, wherein the lower edge of the workpiece, that is to be bevelled, becomes the upper edge. Consequently, the control system performs transformation of the cutting program, and the workpiece measurement as well as its cutting is repeated.

[0008] To achieve high accuracy of the cut workpiece it is necessary to synchronize precisely the cutting tool kinematical chain and the workpiece position measurement system in the coordinate system of the cutting machine. To prevent time consuming adjustment of mechanical nodes, the process is carried out by autocalibration function. The autocalibration is performed so that the control system of the machine based on the instruction of the operator automatically checks actual position of the cutting tool position by means of the cutting tool position calibration station, and by means of the workpiece position calibration station it automatically checks the position of the cutting tool position calibration station. In the case that a deviation occurs, the system is switched to the autocalibration mode. The autocalibration mode is carried out in two phases. In the first phase, the cutting tool end point position calibration station calibrates the end position of the cutting tool, and in the second phase the cutting tool end point position calibration station calibrates the workpiece position calibration station.

[0009] The first phase starts with identification of the actual position of the cutting tool end point at the calibration station sequentially in directions of x , y , z motion axes. The identification results are used for synchronization of the cutting tool coordinate system that is deviated from the required position with the calibration station coordinate system. When the coordinate systems are synchronized, the control system launches the calibration process, in which the cutting head is gradually tilted within the whole range of permissible tilts defined by the working area of the machine. During this process the control system of the machine using the calibration station records data referring to the motion of the cutting tool end point of the cutting head in direction of x , y , z coordinate axes. When the calibration of the cutting head is made precisely, the motions of the cutting tool end point in direction of respective axes are zero. After finishing the calibration the control system evaluates deviations of the cutting tool end point from the exact reference position and calculates the position errors by which the reference positions in respective coordinate axes of

the machine should be corrected in order to achieve the exact position of the cutting tool in the whole range of its tilting positions. When this process is finished, the interpolator of the control system automatically applies the corrections in trajectory generation of the cutting tool end point, whereby the first phase of calibration is completed and the second phase starts.

[0010] The second phase of the calibration includes measurement of the positions of the cutting tool end point position calibration station using the workpiece position calibration station equipped with a laser line scanner provided for different tilting angles within the whole range of rotation of the scanner rotating around its vertical axis (in the figures referred to as a motion direction along C motion axis). After finishing the measurement, the control system evaluates corrections defining the offsets of the coordination system of the workpiece position calibration station with respect to the coordination system of the cutting tool end point position, wherein the control system applies the corrections for identification of dimensions and position of the workpiece to be additionally bevelled in the coordinate system of the cutting tool end point.

[0011] The procedure is a self-learning process - autocalibration of the end point of the cutting tool and the workpiece position calibration station and their mutual positions. The autocalibration eliminates the need of time consuming mechanical adjustment of the cutting tool end point in the cutting head, and the mutual position of the end point of the cutting tool and the laser line scanner of the workpiece position calibration station, thereby significantly speeding up the calibration process of the machine and providing high accuracy of cutting.

[0012] Capability of direct as well as additional cutting of bevels that achieves high precision of cutting significantly increases the productivity of the CNC cutting machine and extends its field of application.

Brief description of drawings

[0013]

Fig. 1 Cutting machine with automatic adjustment of the cutting tool end point position in the cutting head by using autocalibration.

Fig. 2 Possible kinematic structures of the cutting head.

Fig. 3. Typical shapes of bevel cuts.

Examples of the embodiment of the invention

[0014] As an example of an embodiment of this invention is the CNC machine illustrated in Fig. 11, provided with a cutting head 15 that enables tilting of the cutting tools 10 in the cutting process in order to cut workpieces with bevels necessary for following welding processes, wherein the alternative possibilities of implementation of the cutting machine 10 kinematical structure are shown in Fig. 2. Fig. 3 illustrates types of bevel cuts, wherein

Fig. 3a illustrates a V shape cut, Fig. 3b shows an Y shape cut, Fig. 3c displays an X shape cut, and Fig. 3d shows a K shape cut.

[0015] The cutting machine according to the invention consists of lateral sides 1 of the machine provided with longitudinal **X** motion axes along which a gantry 2 is moved by means of drives 5, wherein the gantry is provided with **Y** motion axes in the longitudinal direction, along which the support 3 is moved by the drive 6, wherein the support is provided with **Z** motion axes, along which a cutting head 15 is moved by the drive 7, wherein the cutting head provides tilting of a cutting tool 10, wherein the cutting head 15 is able to move rotary around the **A**, **B** motion axes depending on its actual implementation, i.e. kinematics, wherein the motions are provided with corresponding drives 8, 9; and the workpiece position calibration station 4 attached to the support 3, equipped with a laser line scanner 14 rotatable around a vertical axis, i. e. moving around the **C** motion axis by the drive 13, used for measuring the position of the workpiece; a cutting tool 10 position calibration station 11; control system with interpolator 16; and a working table 12. Fig. 2 shows the cutting head 15 kinematics alternatives that perform the tilting of the cutting tool 10 in the cutting process. The cutting tool 10 position calibration station 11 that carries out measurement of the cutting tool 10 end point position in directions of each **x**, **y**, **z** coordinate axis of the cutting tool is located in the working area of the cutting head 15 and the workpiece position calibration station 4, wherein the output of the cutting tool 10 end point position calibration station 11 and the workpiece position calibration station 4 is connected to the control system with interpolator 16.

[0016] In the case of direct cutting of workpieces with bevels, the cutting machine works in a standard way, i. e. the workpieces are cut from a full sheet of the material disposed on the working table 12 according to a cutting program, wherein the cutting program provides tracking control of the cutting tool 10 along the cut edge once, twice, or three times, depending on the required shape of a bevelled edge. When a straight cut or a V shape cut are made, Fig. 3a - single pass; in the case of a Y shape cut - Fig. 3b and an X shape cut - Fig. 3c, - two passes; and a K shape cut requires three passes, Fig. 3d. In each respective cuts, both the orientation angle of the cutting tool with respect to the material surface and the offset of the end point of the cutting tool towards the contour being cut changes so that the final shape of the edge of the workpiece corresponds to the required shape.

[0017] In the case of additional bevel cutting, the piece is first cut straight, then the operator places the cut workpiece onto the empty working table 12 of the cutting machine and navigates the support 3 with the workpiece position calibration station 4 over the workpiece relocated there. Then from the control system with interpolator 16 the operator launches identification of the workpiece position. In this process, the workpiece position calibration station 4 measures the precise position of the cut work-

piece and the control system with interpolator 16 automatically calculates the rotation angle of the cutting program as well as the new position of the cutting program starting point so that the cutting program is synchronised with the relocated workpiece. After this operation is completed, the operator resumes cutting, while in this phase only bevelled parts are cut on the cut edges of the workpiece. When a Y shape is cut, after cutting the edge the process is completed. For cutting an X shape and a K shape bevels, after the upper edge is cut, the operator turns the workpiece upside-down so that the lower surface of the workpiece gets on the top, wherein the lower edge that is to be bevelled, becomes the upper edge. Consequently, based on the instruction of the operator, the control system with interpolator 16 flips over the cutting program and the calibration and cutting processes are repeated.

[0018] High accuracy of the cutting process in both the direct bevel cutting mode and the additional bevel cutting mode is ensured by the automatic calibration of the cutting machine. After collision or upon instruction of the operator the control system with interpolator 16 by means of the cutting tool position calibration station 11 carries out the automatic checking of the actual position of the cutting tool. In the case that no deviation between the actual position and the reference position has been detected, the cutting process further continues. In the case that some deviation has been detected, the system enters the autocalibration mode. The autocalibration mode starts with identification of the end point position of the cutting tool 10 at the cutting tool position calibration station 11 consecutively in directions of **x**, **y**, **z** coordinate axes. This identification is used for synchronization of the coordinate system of the cutting head 15 with the end point of the cutting tool 10 deviated from the reference position, with the coordinate system of the cutting tool position calibration station 11. After synchronization of the coordinate systems, the end point of the cutting tool 10 is inserted into the cutting tool position calibration station 11 and the control system with interpolator 16 launches the calibration process, wherein the cutting tool 10 is gradually tilted within the range of its possible tilts defined by the working area of the machine. During this process the control system with interpolator 16 records data from the cutting tool position calibration station 11 about the motion of the end point of the cutting tool 10 in directions of **x**, **y**, **z** coordinate axes. For ideal setting of the cutting head, the movements of the end point of the cutting tool 10 in directions of respective axes are zero. After the calibration is completed, the control system with interpolator 16 evaluates the deviations of the end point of the cutting tool 10 from the required precise position and calculates the positional offsets used for correction of reference values of the position in respective coordinate axes of the machine in order to achieve the required position of the end point of the cutting tool 10 within the whole tilting range of the cutting head 15. After finishing the process, during the following cutting the corrections

are automatically applied in generating the cutting tool 10 end-point trajectory by the interpolator of the control system 16.

[0019] The process then continues by the calibration of the workpiece position calibration station 4. Upon instruction of the control system with interpolator 16, the workpiece position calibration station 4 is positioned over the cutting tool 10 position calibration station 11, while the control system with interpolator 16 provides its precise measurement using the workpiece position calibration station 4 for all rotation angles of the laser line scanner 14. Based on the measured data the control system with interpolator 16 evaluates offsets of the coordinate system of the workpiece position calibration station 4 with respect to the coordinate system of the cutting tool 10 for all directions of rotation of the laser line scanner 14. Then the control system with interpolator 16 uses the data for precise identification of the position of the workpiece in the coordinate system of the cutting tool 10. When the calibration of the workpiece position calibration station is finished, the autocalibration process is also completed.

[0020] The CNC machine according to the invention does not need any mechanical adjustment of the cutting tool 10 position in the cutting head 15 or mechanical adjustment of the workpiece position calibration station 4, wherein this is a self-learning process - adjustment of the machine by using the autocalibration.

The list of reference signs:

[0021]

1	lateral sides of the machine	
X	motion axis for motion of the gantry in x axis direction	35
Y	motion axis for motion of the support in y axis direction	
Z	motion axis for motion of the cutting head in z axis direction	40
A	motion axis for tilting the cutting head	
B	motion axis for tilting the cutting head	
C	motion axis for rotary motion of laser line scanner gantry	
2	gantry	
3	cutting tool support	45
4	workpiece position calibration station	
5	gantry drive along X motion axis	
6	support drive along Y motion axis	
7	cutting head drive along Z motion axis	
8	drive of part of the cutting head along B motion axis	50
9	drive of part of the cutting head along A motion axis	
10	cutting tool	
11	cutting tool position calibration station	
12	working table	
13	drive of the laser line scanner along C motion axis	55
14	laser line scanner	
15	cutting head	
16	control system with interpolator	

Claims

1. The CNC machine for cutting with plasma, oxy-fuel, and water jet, capable of direct and additional bevel cutting using autocalibration for self-adjustment, consisting of

- lateral sides (1) of the machine provided with **X** motion axes;
- gantry (2) provided with drives (5), **Y** motion axes for motion of a support (3) provided with the drive (6), **Z** motion axes for motion of a cutting head (15) being able to move rotary along **A**, **B** axes by drives (8, 9) and carrying a cutting tool (10);
- cutting tool position calibration station (11);
- control system with interpolator (16);
- working table (12);

characterised in that the support (3) is equipped with the workpiece position calibration station (4) connected with a laser line scanner (14) having the drive (13) for its rotary motion along the **C** motion axis, **and that** the workpiece position calibration station (11) is located in overlapping of working areas of the cutting head (15) and the workpiece position calibration station (4), wherein the output of the cutting tool position calibration station (11) and the output of the workpiece position calibration station (4) are connected to the inputs of the control system (16) with interpolator being coupled through its outputs with drives (5), (6), (7), (13) of **X**, **Y**, **Z**, **C** motion axes of the machine.

2. The method of automatic calibration of the precise position of the cutting tool in the cutting head (15) of the CNC machine and automatic determination of the precise position of the workpiece position calibration station in the coordinate system of the machine, **characterised in that** the control system with interpolator (16), using the cutting tool (10) position calibration station (11), carries out the measurement of the actual position of the cutting tool (10) end point in the whole range of its possible tilting and rotating, wherein comparing the measured values with the reference ones and calculating the correction values, by which in the following cutting process of the machine, it corrects the reference trajectory generated via its output for drives (5, 6, 7) for respective **X**, **Y**, **Z** motion axes, and then using the workpiece position calibration station (4) it calibrates the precise position of the cutting tool (10) position calibration station (11) in the whole range of rotation of laser line scanner (14) along the **C** motion axis by the drive (13), wherein based on measured values the control system with interpolator (16) calculates values of the offset of the cutting head (15) coordinate system with respect to the workpiece position calibration station

(4) coordinate system and these values are used for correction of the data received from the workpiece position calibration station (4) in evaluation of the actual position of the workpiece in the coordinate system of the machine.

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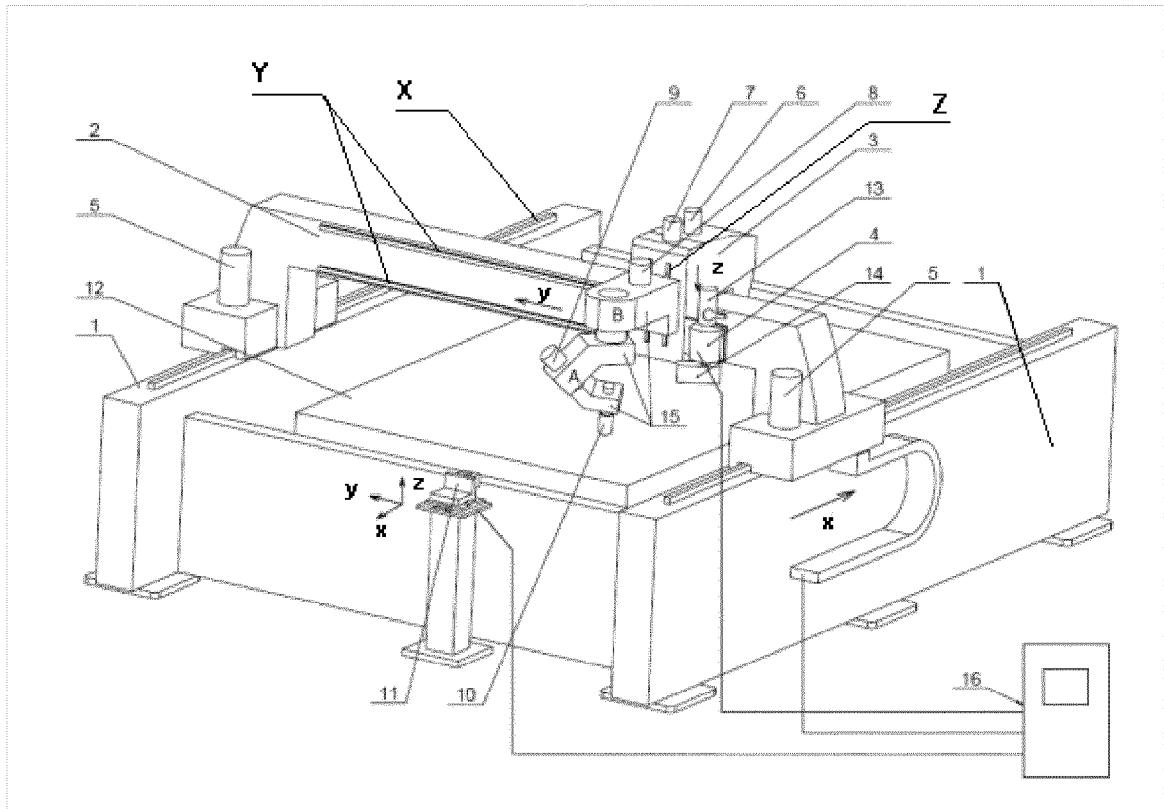


Fig. 1

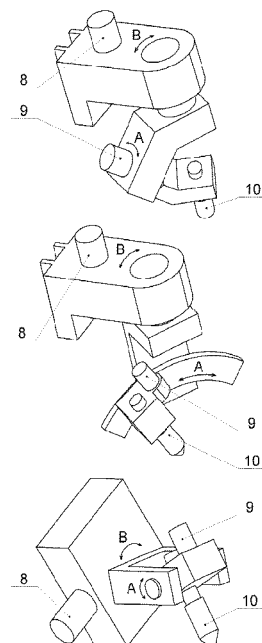


Fig. 2

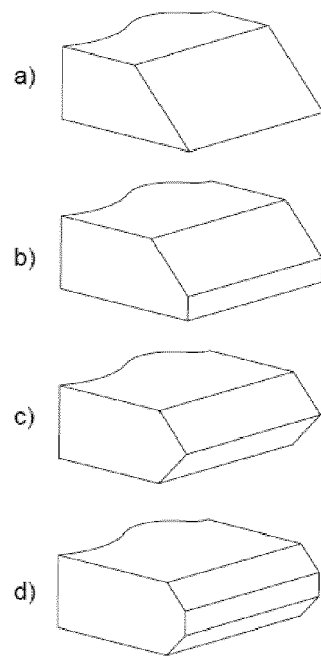


Fig. 3



EUROPEAN SEARCH REPORT

Application Number
EP 14 47 5501

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	EP 2 584 419 A2 (MICROSTEP SPOL S R O [SK]) 24 April 2013 (2013-04-24)	1	INV. G05B19/401
A	* the whole document *	2	
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			TECHNICAL FIELDS SEARCHED (IPC)
			G05B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 18 November 2014	Examiner Messelken, M
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EP 14 47 5501

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