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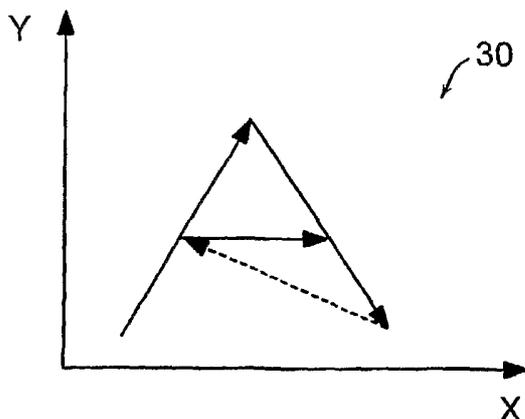
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(54) Title: SYSTEM AND METHOD FOR OPTIMIZING CHARACTER MARKING PERFORMANCE



(57) Abstract: An optimization system is disclosed for optimizing
the performance of a laser processing system that employs a limited
rotation motor. The optimization system includes an input unit for
receiving input parameters including stroke speed, stroke delay, jump
speed and jump delay, and includes an evaluation unit for identifying
one of an optimal stroke speed or stroke quality for achieving a de-
sired processing performance.

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**SYSTEM AND METHOD FOR OPTIMIZING
CHARACTER MARKING PERFORMANCE**

The present application claims priority to U.S. Provisional Patent Application
5 Ser. No. 60/538,842 filed January 23, 2004, and claims priority to U.S. Provisional
Patent Application Ser. No. 60/575,255 filed May 28, 2004, and claims priority to
U.S. Provisional Patent Application Ser. No. 60/613,962 filed September 28, 2004.

BACKGROUND

10 The present invention generally relates to limited rotation motor systems, and
relates in particular to systems for designing limited rotation motor systems.

Limited rotation motors generally include stepper motors and constant
velocity motors. Certain stepper motors are well suited for applications requiring
high speed and high duty cycle sawtooth scanning at large scan angles. For example,
15 U.S. Patent No. 6,275,319 discloses an optical scanning device for raster scanning
applications.

Limited rotation motors for certain applications, however, require the rotor to
move between two positions with a precise and constant velocity rather than by
stepping and settling in a sawtooth fashion. Such applications require that the time
20 needed to reach the constant velocity be as short as possible and that the amount of
error in the achieved velocity be as small as possible. Constant velocity motors
generally provide a higher torque constant and typically include a rotor and drive
circuitry for causing the rotor to rotate about a central axis, as well as a position
transducer, e.g., a tachometer or a position sensor, and a feedback circuit coupled to
25 the transducer that permits the rotor to be driven by the drive circuitry responsive to

an input signal and a feedback signal. For example, U.S. Patent No. 5,424,632 discloses a conventional two-pole limited rotation motor.

Figure 1 shows a marking system 10 that employs two limited rotation motors 12, 14 that are coupled to mirrors 13 and 15 respectively for guiding a laser beam 16 that is produced by a laser source 18 through an imaging lens 20 toward an imaging surface 22. The control of the *x* scan direction motor 12 and the *y* scan direction motor 14, as well as the turning on and off of the laser source 18 is provided by a controller 22. The controller 24 receives input commands 26 regarding a mark that is to be made on the imaging surface. The controller 24 then directs the *x* scanner 14 and the *y*-scanner 12 to move accordingly, and to turn on and off the laser source (e.g., to switch between a low and high or above a marking threshold value) responsive to the input command and responsive to the movement of the imaging surface at the target plane. The system may also include position detectors within each motor 12 and 14 that each provide position detection signals back to the controller 24.

Such limited rotation motors may be used, for example, in a variety of laser scanning applications, such as high speed surface metrology. Further laser processing applications include laser welding (for example high speed spot welding), surface treatment, cutting, drilling, marking, trimming, laser repair, rapid prototyping, forming microstructures, or forming dense arrays of nanostructures on various materials.

The processing speeds of such systems are typically limited by one or more of mirror speed, X-Y stage speed, material interaction and material thermal time constants, the layout of target material and regions to be processed, and software performance. Generally, in applications where one or more of mirror speed, position

accuracy, and settling time are factors that limit performance, any significant improvement in scanning system open loop gain may translate into immediate throughput improvements.

In the limited rotation motor actuator, the open-loop gain is determined by the torque constant of the motor, the inertia of the mirror and rotor structure, and the gain characteristics of the power amplifier. Change in the design of the system, such as changes of head from one size to another size, may cause significant changes in total inertia, and consequently the open-loop gain. Such systems, however, typically must be designed and constructed in order to fully evaluate their performance.

There is a need, therefore, for improved limited rotation motor system, and more particularly, there is a need for optimizing the performance of limited rotation motors.

SUMMARY

The invention provides an optimization system for optimizing the performance of a laser processing system that employs a limited rotation motor in accordance with an embodiment. The optimization system includes an input unit for receiving input parameters including stroke speed, stroke delay, jump speed and jump delay, and includes an evaluation unit for identifying one of an optimal stroke speed or stroke quality for achieving a desired processing performance. In accordance with various further embodiments, the evaluation unit identifies an optimal marking speed for achieving a desired marking quality, and in further embodiments, the evaluation unit identifies an optimal marking quality for achieving a desired marking speed.

BRIEF DESCRIPTION OF THE DRAWINGS

The following description may be further understood with reference to the accompanying drawings in which:

5 Figure 1 shows an illustrative diagrammatic view of a scanning or marking system of the prior art;

 Figure 2 shows an illustrative diagrammatic view of marking and jump vectors for forming the letter A in accordance with an embodiment of the invention;

 Figures 3A and 3B show diagrammatic illustrative views of the x and y
10 position commands over time in forming the mark shown in Figure 2;

 Figures 4A and 4B show diagrammatic illustrative views of the x and y actual motor commands responsive to the position commands of Figures 3A and 3B for a set of marking parameters;

 Figure 5 shows an illustrative diagrammatic view of a mark formed by the
15 actual motor commands shown in Figures 4A and 4B;

 Figures 6A and 46B show diagrammatic illustrative views of the x and y actual motor commands responsive to the position commands of Figures 3A and 3B for another set of marking parameters;

 Figure 7 shows an illustrative diagrammatic view of a mark formed by the
20 actual motor commands shown in Figures 6A and 6B;

 Figures 8A and 8B show illustrative diagrammatic views of character marking in a system in accordance with an embodiment of the invention at relatively low and high speeds;

Figure 9 shows an illustrative diagrammatic view of the identification of error vectors in quantifying the quality of a mark in accordance with an embodiment of the invention;

Figure 10 shows an illustrative diagrammatic view of the identification of error vectors in quantifying the quality of another mark in accordance with an embodiment of the invention;

Figure 11 shows an illustrative diagrammatic graphical representation of marking quality quantification analyses in accordance with certain embodiments of the invention;

Figure 12 shows an illustrative diagrammatic graphical representation of a marking speed optimization mapping in accordance with an embodiment of the invention;

Figure 13 shows an illustrative diagrammatic graphical representation of a marking speed optimization mapping in accordance with another embodiment of the invention;

Figures 14A - 14C show illustrative diagrammatic views of markings at different parameter settings in accordance with an embodiment of the invention;

Figures 15A and 15B show illustrative diagrammatic views of markings employing further parameter settings in accordance with an embodiment of the invention; and

Figure 16 shows an illustrative diagrammatic view of a virtual marking system in accordance with an embodiment of the invention.

The drawings are shown for illustrative purposes only.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

In accordance with various embodiments of the invention, motor performance in a limited rotation motor system is optimized either for speed or for quality by identifying a particular combination of marking speed (MS), marking delay (MD), jump speed (JS), jump delay (JD), and Laser on-off delay (Lon/off) that achieves the highest speed or quality. The combination of factors that yields the output performance is identified by obtaining a real or virtual image, and comparing the real or virtual image with the input commands for a particular mark or character. The comparison identifies a set of differences between the input data and the real or virtual image for a collection of points on the input data. The system then either obtains an average of the differences for a mark or character (average marking error) or obtains the largest single marking error (maximum marking error). The combination of factors (MS, MD, JS, JD, Lon/Loff) that yields the smallest error for either speed or quality is then chosen.

A system and method, therefore, are provided to optimize the performance of a two-dimensional laser marking system. The marking system in accordance with an embodiment includes two optical scanners. Each scanner includes a limited rotation motor as the actuator. An optimization technique based on this is performed by marking simulations with a model derived from a marking head. For a given pattern, the optimized command sets are determined from simulated marking results of all practical settings of command parameters. Marking quality optimization is achieved by choosing the best quality marking among all markings of the same speed, while marking speed optimization is obtained by searching the highest marking speed that maintains a specified marking quality. Simulation and experimental results show up to 40% improvement in the marking speed, or four times improvement on marking quality, as compared with the standard zero mark command sets.

Laser marking systems are widely used in industries with applications ranging from marking labels on the semiconductor wafer to engines of very large trucks. In these applications, marking is performed by deflecting the incoming laser beam with two individually controlled mirrors to create horizontal and vertical movements of the beam spot on the marking surface. Usually the mirrors are driven by a specially designed direct current (DC) limited rotation torque motor sometimes called a galvanometer. The speed of marking a given pattern is limited by the speed of the servo system with the motor. With the continuing demand for more efficient production of limited rotation motors, improving the marking speed while maintaining a specified marking quality has become a challenge for marking system designs and users.

From a control system perspective, a laser marking system may be characterized as a servo motor system wherein the marking laser beam is required to follow faithfully to the set of strokes that draw the desired pattern. Although the quality of the marking is related to the overall tracking errors, it is the differences between the reference marking pattern and the actual marking that determines the quality of the marking. Since the actual marking consists of only portions of the overall time response of the scanner movement, the optimization schemes that minimize overall tracking errors may not result in the optimal marking performance of the marking system.

Two functions proposed herein may be used in accordance with various embodiments of the invention to evaluate the performance of the marking system based on the quality of the actual marking: these are the maximum marking error (MME) and the average marking error (AME).

To generate the marking commands for a given marking pattern, the pattern may be broken up into small line segments called strokes. Each stroke includes a constant speed ramp command followed by a fixed delay time. The speed of the ramp is called Mark Speed (MS), and the delay time is called Mark Delay (MD). Methods
5 are proposed herein to select the optimal MS and MD setting for a given marking head and marking pattern using marking quality evaluation functions.

An X-Y laser marking system in accordance with an embodiment includes two scanners. The horizontal axis of the marking spot may be defined as the X-axis and the vertical axis may be defined as the Y-axis. The scanner in each axis consists of a
10 limited rotation torque as the actuator, a mirror as a beam deflecting device and associated control and driver electronics. A focusing lens may also be inserted in the beam path between the target plane and the Y-axis mirror to reduce the spot size and increase the energy density of the laser spot.

During laser marking, the laser beam is projected from the laser head onto the
15 target to be marked, called marking plane. The X and Y mirrors in the path of the laser beam control the position of the beam spot on the marking plane by the rotation angles of the X and Y scanner, respectively. Marks are created at the interaction points between the target material and the laser.

The position reference commands to each scanner for marking a given pattern
20 are continuous waveforms of desired angular positions of the X and Y scanner. These position reference commands are generated from a set of stroke vectors and the mark speed and mark delay settings. Each stroke vector is a straight-line segment from which the whole pattern is constructed. If we project the pattern on the complex plane, the segments may be visualized as a vector with the direction of the vector
25 represents the moving direction of the laser beam during marking. Since the pattern

to be marked is represented by a sequence of small vectors, this type of laser marking is also called vector marking.

For example, the sequence of vectors that results in capital letter A is shown at 30 in Figure 2. Each vector is then converted into a ramp signal in the time domain with ramp speed controlled by mark speed (MS). At the end of each ramp command, there is an optional stop period, defined as mark delay (MD). Figure 3A shows the X-axis commands for marking the letter A in Figure 2. In particular, as shown in Figure 3A, the scanner moves the beam along the X-axis for a first time period as shown at 32, the stops for a delay period as shown at 34, then marks again in the positive direction along the X-axis as shown at 36, then rests as shown at 38, then moves in the negative direction along the X-axis as shown at 40, then rests as shown at 42, and then marks in the positive direction along the X-axis as shown at 44, and then rests as shown at 46.

Figure 3B shows the Y-axis commands for marking the letter A in Figure 2. In particular, as shown in Figure 3B, the scanner moves the beam along the Y-axis for a first time period as shown at 50, the stops for a delay period as shown at 52, then marks in the negative direction along the Y-axis as shown at 54, then rests as shown at 56, then moves in the positive direction along the Y-axis as shown at 58, then rests as shown at 60.

Note that the MS and MD settings are global settings. In other words, the same MS and MD values are used for all the vectors in the pattern. The total time from the beginning of marking to the end of marking determines the speed of marking the given pattern. Larger MS and smaller MD for the same vector sequence results in higher marking speed, but larger MS may also result in significant degradation of quality.

For example, Figures 4A and 4B show desired and actual marking commands for forming the marking A shown in Figure 2. Figure 4A shows the marking commands 70 and resulting actual commands 72 for the X-axis when the mark delay (MD) is increased. Figure 4B shows the marking commands 74 and resulting actual commands 76 for the Y-axis when the mark delay (MD) is increased. As shown at 78 in Figure 5, the mark resulting from the actual commands shown at 72 and 76 in Figures 4A and 4B result in a mark that has areas of increased radiation (as shown at 79) associated with the areas of the delays.

Figures 6A and 6B show desired and actual marking commands for forming the marking A shown in Figure 2 in which the mark speed (MS) is increased. Figure 6A shows the marking commands 80 and resulting actual commands 82 for the X-axis when the mark speed (MS) is increased, and Figure 6B shows the marking commands 84 and resulting actual commands 86 for the Y-axis when the mark speed (MS) is increased. As shown at 88 in Figure 7, the mark resulting from the actual commands shown at 82 and 86 in Figures 6A and 6B result in a mark that has overruns (as shown for example at 89) and under-marking (as shown at 90). A balance between these extremes, therefore is desirable.

Because servo systems have finite tracking capabilities, for a fixed MD value, the higher the MS value, the faster the marking speed. However, the higher marking speed is achieved at the expense of a degraded marking quality. Figures 8A and 8B show scanned images of actual markings of the same pattern at two different speeds with MD equal to zero. It is observed that the pattern 92 marked at lower speed in Figure 8A has higher quality with better defined corners in each character than the pattern 94 marked at higher speed as shown in Figure 8B.

Since the marking speed is determined not only by the MS value but also by the MD value, there are many combinations of the MS and MD values that result in the same marking speed (i.e., total marking speed = MS + MD and total jump speed = JS + JD). Applicant has discovered that there exists a set of MS and MD that gives the best marking value. It is also desirable in some applications to find the maximum marking speed achievable at an accepted marking quality level.

The basic concept of evaluating marking quality is to compare the resulting marking with the reference pattern. This is achieved by reconstructing the reference pattern and the actual marked pattern from its corresponding time sequences. The trajectories of the actual marking are derived from only portions of the time responses of the scanner heads. This is because in character marking, as in many other vector marking applications, the laser beam is turned off for some moves of the scanner. The vector with dashed line in Figure 2 is an example of such a move or jump.

To quantify the marking errors, we divide each continuous marking spatially into equal length sections and form error vectors by connecting the corresponding division points between the reference marking and the actual markings.

For example, as shown in Figure 9, the commands for a marking (as shown at 96) may be compared with the actual marking (shown at 98) at a plurality of points (shown at 100). In accordance with an embodiment, the marking 96 may be physically recorded in an imaging medium at a slow total speed (mark speed plus mark delay), and the actual marking 98 may also be physically recorded in the imaging medium as well. The two recordings may be scanned and compared as discussed below. In accordance with further embodiments, the marking 96 may be created as a mathematical representation knowing the commands that are input to the system to create the mark. In this example, the actual markings 98 may be

constructed from the drive signals that are provided to the X and Y motors. In accordance with further embodiments, the actual markings 98 may be generated without using a motor at all, but rather performing mathematical analyses that model the specific motors using specific parameters.

5 The differences (or error vectors) between the markings 96 and 98 at the error points may be generated by choosing an increment value for spacing between error vectors. For example, In accordance with an embodiment, the system may characterize each stroke of the markings 96 as a string of positions. The beginning and end of each stroke is identified, and the mid point along the stroke is also
10 identified. If the stroke is rather long, the process may again identify a mid point in each half of the full stroke. The system would then characterize each stroke of the markings 98 as a string of positions and identify the ends and midpoint(s) as appropriate and as done with the markings 96. Each error vector is then defined as the distance between corresponding points on the markings 96 and 98.

15 For example, Figure 10 shows an illustrative diagrammatic view of a reference mark 102 (in the form of a rectangle) and an actual mark 104. The end points of a first stroke are identified as 101 and 103. The midpoint of this stroke is identified and each half is again divided as the stroke is rather long. The corresponding strokes of the actual mark 104 are also similarly divided into end and mid-points, and the error
20 vectors are identified as extending between associated points. For example, the error vector 106 extends between first end points of the first stroke of each of the reference mark 102 and the reference mark 104. Such end point error vectors are identified, for example, at 106, 110, 114 and 118. Mid-point error vectors are identified at 107, 108, 109, 112, 115, 116, 117 and 120. The process of constructing the MME involves
25 finding the maximum error (e.g.,110) and the process of constructing the AME

involves finding the average of the 12 error vectors. If the number of mid-points becomes very high, the AME approaches the area between the reference mark 102 and the actual mark 104.

In accordance with further embodiments, error vectors may be determined in a grid pattern that covers the mark with a uniform spacing between each point of about 10 to 1000 micrometers. These error vectors may be quantified in a variety of ways. Again, the lengths of these error vectors defined indicate the deviations of the actual marking from the reference marking.

Two evaluation functions of marking qualities may be employed to quantify the error vectors: Maximum Marking Error (MME) is defined as the maximal length of all the error vectors, while Average Marking Error (AME) is defined as the average of the lengths of all the error vectors. The MME, therefore, is the maximal deviation of the actual marking from the ideal marking. The AME, on the other hand, represents the marking errors for the entire pattern. In fact, for sufficiently large division numbers, AMR indicates the total area of the band formed by the reference marking and actual marking.

With the evaluation function defined, the optimal command sets for a given pattern may be determined by comparing the quality evaluation function values among all possible markings. Specifically, markings with different MS and MD settings for the desired pattern may be simulated, the marking speed together with the marking quality defined by the evaluation function values may be recorded.

For quality-optimal markings the command sets may be selected that give the smallest evaluation function numbers at a specified marking speed. For speed-optimal markings, the command set may be chosen that yields the highest marking speed at a pre-defined quality level.

Simulation and experimental results of command set optimization on commercially available marking heads show that scanning system may be optimized in accordance with the invention. The scanner model used in marking simulation is derived from the marking head used using system identification techniques. A string of "ABCDEFGHIJ" is used in the marking. Marking speed and marking delay settings are normalized. Larger values in MS and MD represent higher marking speed and longer mark delay period respectively. The marking quality values, i.e., MME and AME values, are normalized by the height of the characters marked and converted in decibels.

10 In marking quality optimization, the marking quality values MME and AME are calculated for all practical combinations of MS and MD that result in the given marking speed. Figure 6 shows the MME (at 126) and AMR (at 128) vs. MD at marking speed 617cps (characters-per-second). Compared with the standard command set with MD equals 0, we can see that the minimal marking error is
15 obtained at the MD values around 0.5. This MD value corresponds to the MS settings of 1.4 times of the MS settings in the case of MD equals 0. With the optimal command set MME and AME are reduced by a factor of 4 and 2, respectively. Note that MME and AME reach minimal at very close regions of MD.

Figure 12 shows in the area indicated at 130 MME for all the practical
20 combinations of MS and MD that result in different marking speeds. Figure 13 shows in the area indicated at 132 AME for all the practical combinations of MS and MD that result in different marking speeds. To find the maximal marking speed at a given marking quality, the lower boundary of the plot at the given marking quality value may be identified. For example, with the standard command set with MS=1 and
25 MD=0 and marking speed 618cps, MME equals -22dB. At this quality level, the

maximal marking speed can be achieved at 869cps. This is a 40% improvement in marking speed.

Figures 14A - 14C show simulated markings that results with and without the optimized command set. Figure 14A shows (at 140) the standard command setting with MD=0. Figure 14B shows (at 142) the optimized marking quality at the same speed as Figure 14A, while Figure 14C shows (at 144) the markings at 869cps at the quality of the markings in Figure 14A.

Figures 15A and 15B show the experimental results with a commercially available marking head for speed optimizations. The original marking speed for the marking (as shown at 150) in Figure 15A is 935cps, while the optimized marking speed for the marking (as shown at 152) in Figure 15B is 1110cps. The invention provides, therefore, a method of improving the character marking performance through command set optimization in accordance with various embodiments.

In accordance with another embodiment, the invention provides that the quality of a marking may be quantified by comparing the desired marking with a virtual marking rather than an actual marking. A virtual marking is one that is determined through mathematical modeling to represent the actual marking in a particular system under a particular set of parameters.

Upon quantifying the quality of a marking, the system may incrementally adjust one of MS, MD, JS, JD while maintaining either speed or quality fixed to determine the optimal set of parameters. The process is then repeated until the desired performance characteristic (speed or quality) begins to fall. In other embodiments, the system may employ a look-up table of previously recorded values, and simply look up the highest achievable speed or quality for the desired performance.

A virtual marking system is shown in Figure 16. Input commands are provided to a virtual limited rotation motor controller, and the virtual limited rotation motor controller provides output commands to a virtual motor, output shaft and mirror system. A position detection system records the position detection signals at the times
5 that a laser would have been on, and thereby determines a virtual laser marking image.

A computer model, therefore, simulates the laser marking system. The virtual optical marker converts a specified pattern to be marked into the image of a marked pattern together with various real time signals of the marker in marking the given
10 pattern. As shown in Figure 16, the system 160 includes a command generation and laser control unit 162 that provides pattern generation and laser control to translate a given multi-dimensional image into time sequences of mirror position commands together with laser control commands. The command generation and laser control unit 162 generates a command history and the laser control signal as shown at 163.
15 The images of the marking are obtained by combining the laser control signal, beam trajectory, the laser type and the material to be marked.

The system 160 also includes a closed loop actuator system 164 that simulates the dynamic response of the beam-deflecting surfaces actuated by the motors, as well as optical-mechanical models or components 166 are employed to translate the mirror
20 angle into beam trajectories on the target surface. The laser marking system receives customer adjustable scanning parameters via a parameter input unit 168 and a pattern to be marked via a pattern input 170. The closed-loop actuator system 164 provides the motor current, power, and angular position trajectory as shown at 172.

The optical-mechanical components provide laser beam trajectories on
25 mirrors, lenses and the target as shown at 174. The system 160 may also include a

laser system 176, and the system provides images of the marked patterns as shown at 178.

The independent laser control signal is derived as a timed data sequence representing the one and off status of the laser at any given time during the marking process. The motor system model simulates the time responses of the X and Y motor systems subject to the input command generated above. The primary output of the motor system model is the angular displacement of the X and Y mirrors represented by an array of angular position data together with the corresponding time values. Additional output from the motor system includes real time motor current and power dissipation of the motor system.

The optical path of the laser beam may be as shown in Figure 1 including a laser beam of a given diameter, optical lenses having defined characteristics, and relative positions among the mirrors, laser, lens, and target surface. The light intensity distributions on the mirror, lens and the target surface are also known. The laser beam is modeled by a Gaussian intensity pattern and is propagated along the path of the beam.

By combining the laser control signal and the mirror position trajectories, the laser light intensity profile trajectories on the mirror, lens and target surface may be constructed mathematically. The marked image is then obtained by shape and/or material property changes on the target surface as the result of the interaction between the surface material and laser intensity changes during the marking process.

The customer adjustable scanning parameters may include mark speed, which is the speed of the reference beam during marking, mark delay, which is the wait period at the end of each marking, jump speed, which is the speed of the reference beam during jump, jump delay, which is the wait period at then end of each jump,

laser-on delay, which is the time difference between the beginning of reference marking and turning the laser beam on, and laser-off delay, which is the time difference between the end of reference marking and turning the laser beam off.

During operation, the specified pattern to be marked is first converted into a
5 sequence of a laser beam positions. Next, the desired laser beam position is translated into angular positions of the X and Y axis mirror using the user specified marking parameters, including marking speed, mark delay, jump speed and jump delay. The desired mirror angular position commands are represented by an array of position values together with the corresponding time values. A pattern to be marked may be
10 defined as the desired trajectory of the mirror positions with its corresponding mark and jump control.

The command generation and laser control unit 162 converts the pattern into the position commands to the scan head using the user defined scanning parameters, i.e., MS, MD, JS, JD, Laser-On and Laser-Off. These commands are represented by a
15 time-stamped sequence of reference mirror positions of both the X and Y axis. The sequence of laser on/off control is also generated using the Laser-On and Laser-Off control parameters. Note that the following relationships exist between the above parameters: $MS*MS=MSx*MSx + MSy*MSy$ and $JS*JS=JSx*JSx + JSy*JSy$.

The positions of the X and Y mirrors are generated using the closed-loop
20 system model of the motor system. There are different ways of representing the system model for the purpose of simulating the time response of the optical scanners. These include a set of differential/difference equations, transfer functions, state space matrices, frequency response data, and graphical system models such as the model discussed below.

The mathematical model of the closed-loop motor system 164 may either be derived from physical laws or be identified from real system measurements, or may be formed as a combination of both. The purpose is to simulate the dynamic response of the motor system when commanded with the command signals generated by the
5 command generation and laser control system 162.

The optical-mechanical components 166 convert a given mirror position into the position of the laser beam on the marking surface. This is done by modeling the laser beam from the laser source as a set of parallel lines in the space. The mirrors are then modeled as the planes in the space. First, the beam landing on the focusing lens
10 is calculated as lines reflected by two planes defined by the x and y mirror positions. Next, beam position and shape on the marking surface is calculated using the optical equations that govern the lens used. For example, for standard lenses, the in and out beam follows the cosine rule, and the F-theta lenses, the out beam angle is proportional to the angle of the in beam. Laser control is used in determining whether
15 or not a beam spot should be formed on the marking surface.

The trajectory of the laser spot on the marking surface is then used to form the image of markings. This is done by linear superposition of beam spots of all the beams landed on a given area of the marking surface during the entire process of marking.

20 Mathematically, this is done by a multidimensional convolution.

Those skilled in the art will appreciate that numerous modifications and variations may be made to the above disclosed embodiments without departing from the spirit and scope of the invention.

What is claimed is:

- 1 1. An optimization system for optimizing the performance of a laser processing
2 system that employs a limited rotation motor, said optimization system comprising:
3 input means for receiving input parameters including stroke speed, stroke
4 delay, jump speed and jump delay; and
5 evaluation means for identifying one of an optimal stroke speed or stroke
6 quality for achieving a desired processing performance.
- 1 2. The optimizing system as claimed in claim 1, wherein said evaluation means
2 identifies an optimal marking speed for achieving a desired marking quality.
- 1 3. The optimizing system as claimed in claim 1, wherein said evaluation means
2 identifies an optimal marking quality for achieving a desired marking speed.
- 1 4. The optimization system as claimed in claim 1, wherein said optimization
2 means further includes tuning means for changing at least one of the stroke speed,
3 stroke delay, jump speed and jump delay responsive to the evaluation means.
- 1 5. The optimization system as claimed in claim 1, wherein said evaluation means
2 includes means for determining an average marking error.
- 1 6. The optimization system as claimed in claim 1, wherein said evaluation means
2 includes means for determining a maximum marking error.
- 1 7. The optimization system as claimed in claim 1, wherein said system includes
2 actual marking means for providing actual marking data to be evaluated by the
3 evaluation means.

1 8. The optimization system as claimed in claim 1, wherein said system includes
2 virtual marking means for providing virtual marking data to be evaluated by the
3 evaluation means.

1 9. An optimization system for optimizing the performance of a laser marking
2 system that employs a limited rotation motor, said optimization system comprising:
3 parameter input means for receiving input parameters including marking
4 speed, marking delay, jump speed and jump delay;
5 pattern input means for receiving data representative of a pattern to be marked;
6 and
7 evaluation means for identifying one of an optimal marking speed or marking
8 quality for achieving a desired marking performance by comparing the pattern to be
9 marked with a marked pattern data that is representative of a marked pattern to be
10 produced by the laser marking system responsive to the pattern to be marked.

1 10. The optimizing system as claimed in claim 9, wherein said evaluation means
2 identifies an optimal marking speed for achieving a desired marking quality.

1 11. The optimizing system as claimed in claim 9, wherein said evaluation means
2 identifies an optimal marking quality for achieving a desired marking speed.

1 12. The optimization system as claimed in claim 9, wherein said optimization
2 means further includes tuning means for changing at least one of the marking speed,
3 marking delay, jump speed and jump delay responsive to the evaluation means.

1 13. The optimization system as claimed in claim 9, wherein said evaluation means
2 includes means for determining an average marking error.

1 14. The optimization system as claimed in claim 9, wherein said evaluation means
2 includes means for determining a maximum marking error.

1 15. The optimization system as claimed in claim 9, wherein said system includes
2 actual marking means for providing actual marking data to be evaluated by the
3 evaluation means.

1 16. The optimization system as claimed in claim 9, wherein said system includes
2 virtual marking means for providing virtual marking data to be evaluated by the
3 evaluation means.

1 17. The optimization system as claimed in claim 9, wherein said evaluation means
2 includes error vector generation means for generating error vectors that are
3 representative of differences between data representative of the pattern to be marked
4 and the marked pattern data.

1 18. A method of tuning a laser marking system that includes a limited rotation
2 motor, said method comprising the steps of:
3 receiving input parameters including marking speed, marking delay, jump
4 speed and jump delay;
5 receiving data representative of a pattern to be marked and
6 identifying one of an optimal marking speed or marking quality for achieving
7 a desired marking performance by comparing the pattern to be marked with a marked
8 pattern that is produced by the laser marking system responsive to the pattern to be
9 marked.

1 19. The method as claimed in claim 18, wherein said step of identifying one of an
2 optimal marking speed or marking quality for achieving a desired marking
3 performance involves identifying an optimal marking speed for achieving a desired
4 marking quality.

1 20. The method as claimed in claim 18, wherein said step of identifying one of an
2 optimal marking speed or marking quality for achieving a desired marking
3 performance involves identifying an optimal marking quality for achieving a desired
4 marking speed.

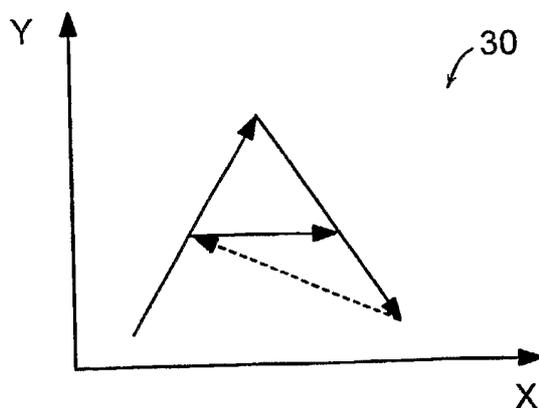


FIG. 2

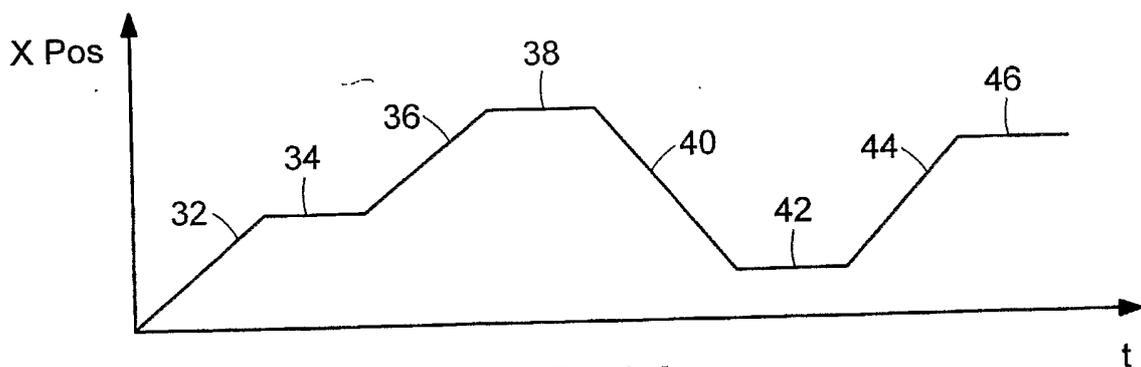


FIG. 3A

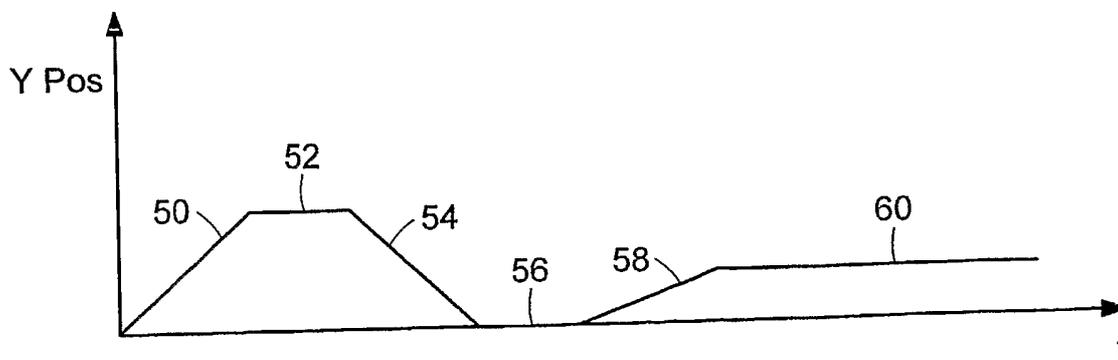


FIG. 3B

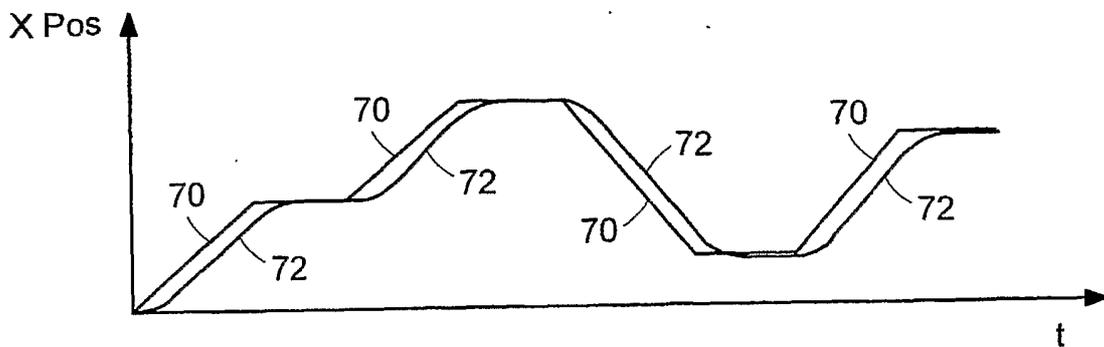


FIG. 4A

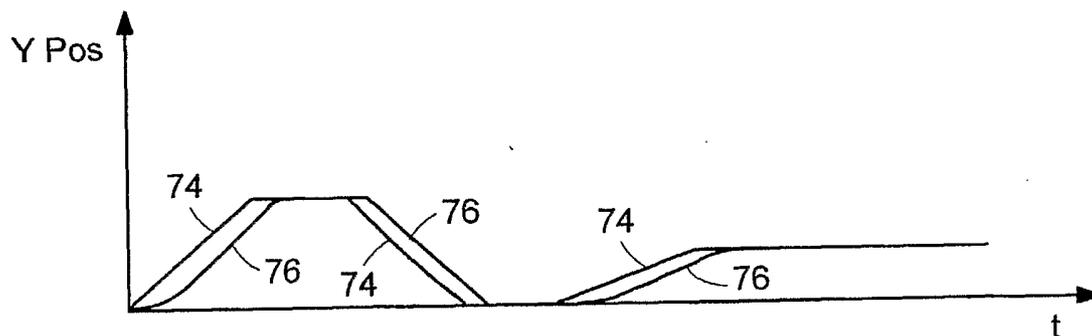


FIG. 4B

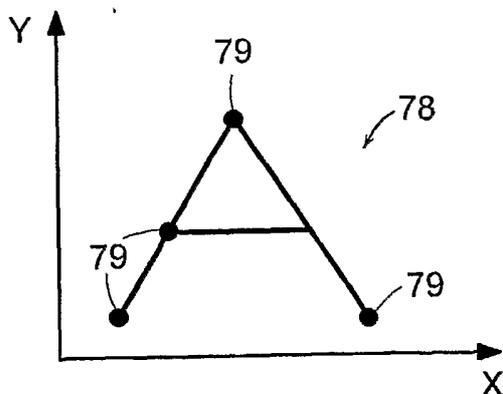


FIG. 5

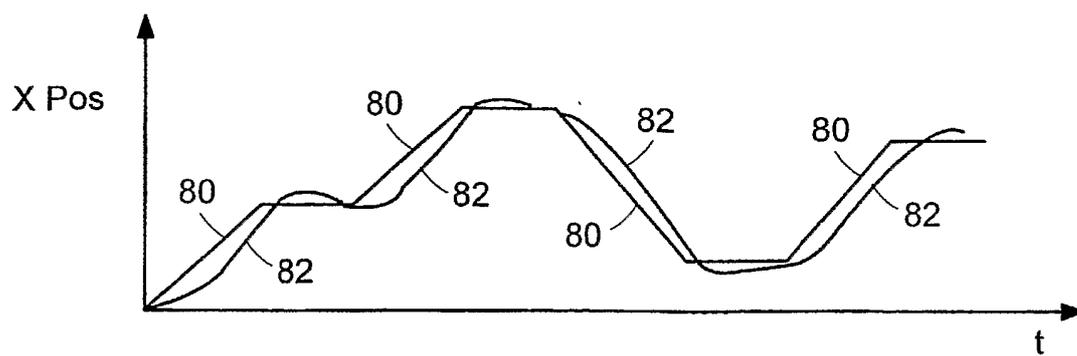


FIG. 6A

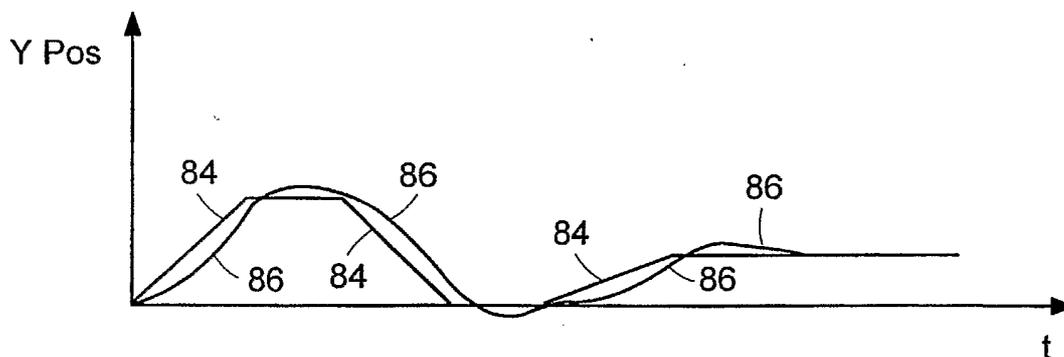


FIG. 6B

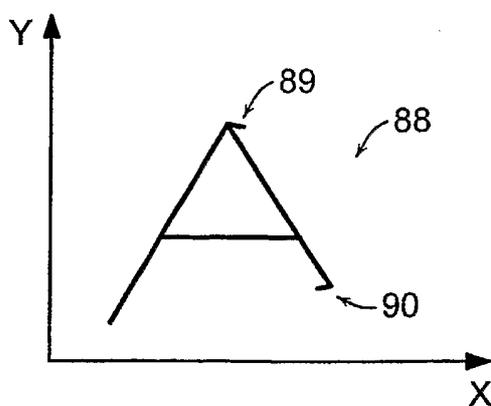


FIG. 7



FIG. 8A



FIG. 8B

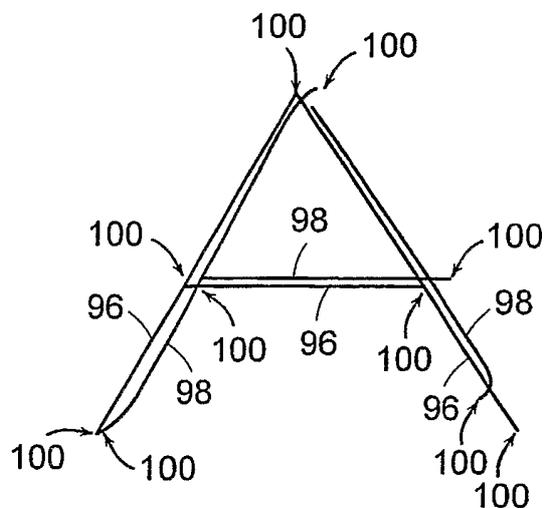


FIG. 9

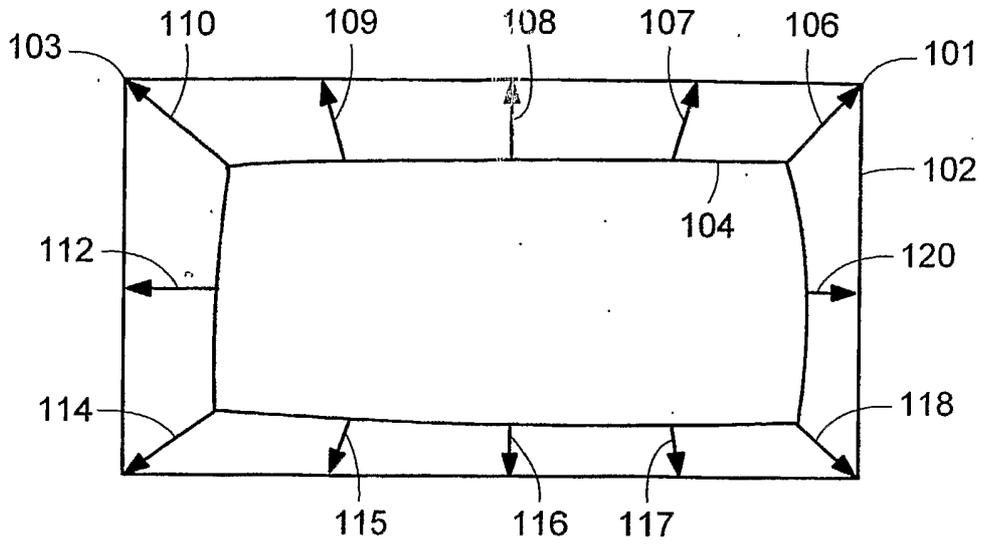


FIG. 10

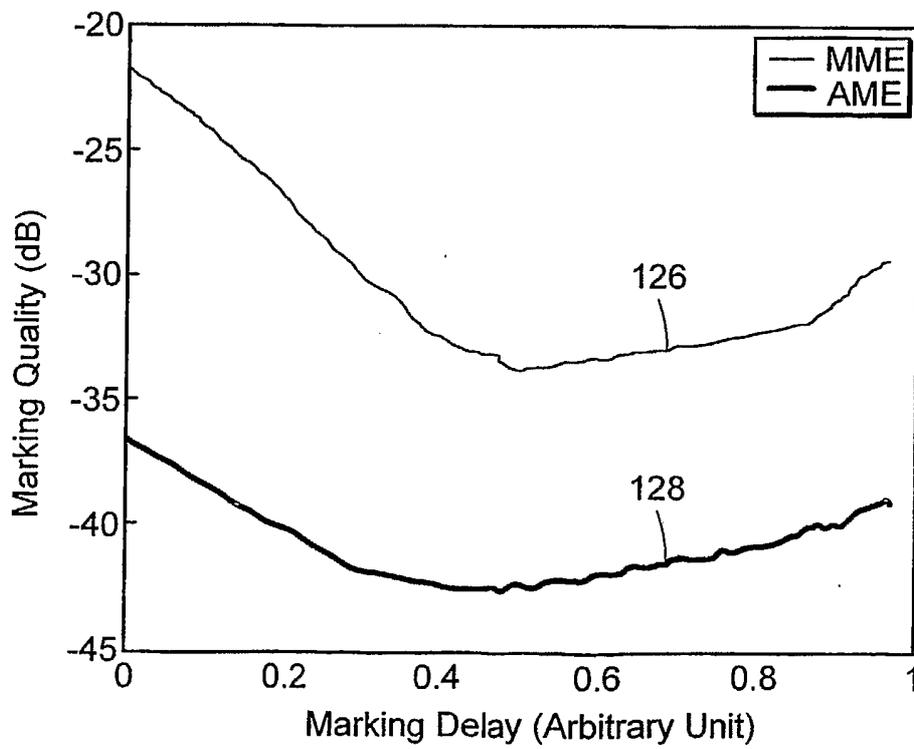


FIG. 11

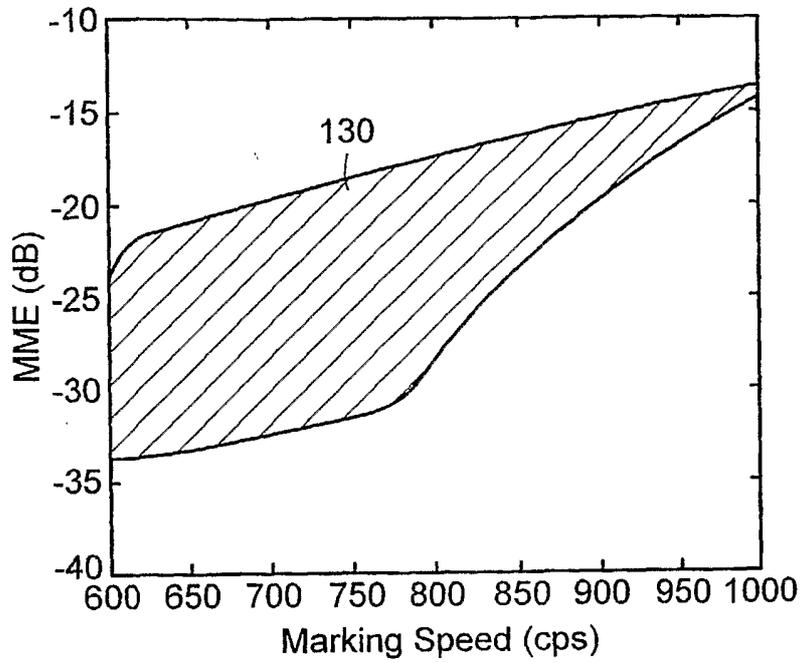


FIG. 12

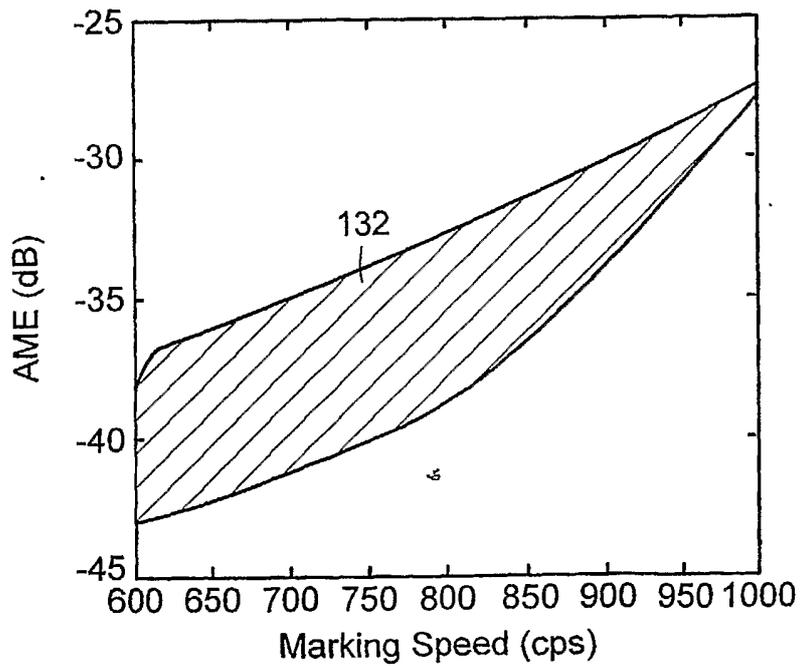


FIG. 13



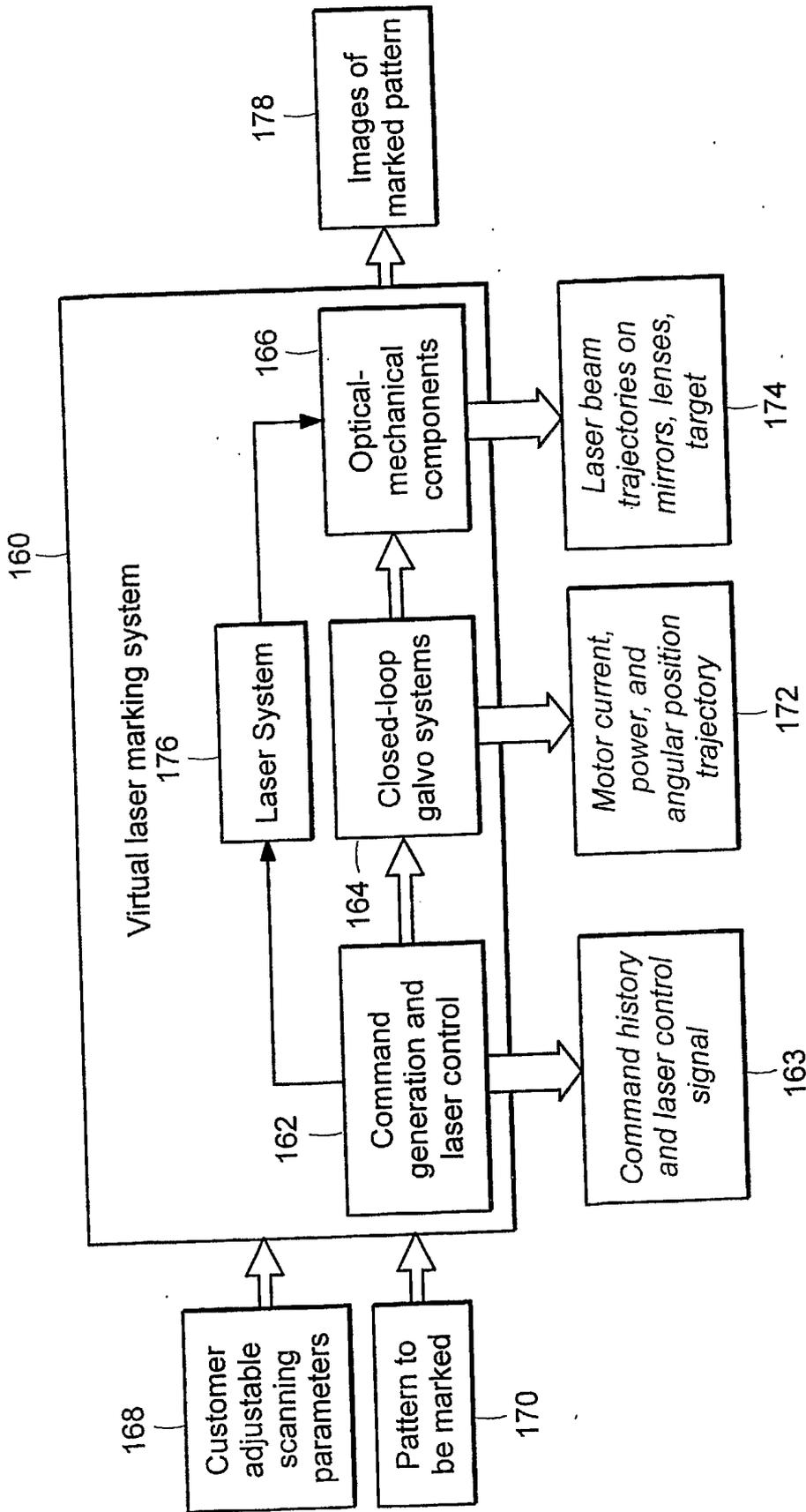


FIG. 16

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/002009

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 7 G02B26/10 G02B26/08 B23K23/00 B23K26/08 B41M5/24
 B41M5/26 G06K1/12 H02P6/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
 Minimum documentation searched (classification system followed by classification symbols)
 IPC 7 G02B B23K B41M G06K H02P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
 EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 5 185 676 A (NISHIBERI ET AL) 9 February 1993 (1993-02-09) abstract; figures -----	1-20
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Date of the actual completion of the international search 27 May 2005	Date of mailing of the international search report 14/06/2005
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Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Ward, S
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INTERNATIONAL SEARCH REPORT

 International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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International Application No

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