

-1-

MULTI-POINT BENDING OF BARS DURING FABRICATION OF MAGNETIC RECORDING HEADS

BACKGROUND OF THE INVENTION

The present invention relates generally to the
5 fabrication of magnetoresistive (MR) and inductive
recording sensors or transducers for data storage
application. More specifically, the present invention
relates to a method and apparatus for bending a bar
which carries a plurality of sliders at multiple points
10 during the fabrication process and specifically during
the lapping process.

During the fabrication of magnetic heads for
use in magnetic data storage applications, an array of
transducers are fabricating on a common substrate (also
15 called a wafer) by depositing a plurality of layers onto
a surface of the substrate. The array of transducers
are patterned using, for example, a photolithographic
process in combination with various etching and liftoff
processes. The finished substrate or wafer is then
20 optically and/or electrically inspected and subsequently
cut into smaller arrays, typically a plurality of bars,
i.e. rows of transducers. Next, the individual rows or
bars of transducers are machined or "lapped" to obtain
a desired dimension. (Lapping is a material removal
25 process described below in more detail.) For MR
transducers, this dimension is sometimes referred to as
stripe height (SH) and for inductive transducers this
dimension is sometimes referred to as throat height
(TH). Often, electrical lap guides (ELGs, described
30 below) are deposited upon the same substrate and are
used as sensors during the lapping process. Following
the lapping process, the recording heads are diced to
produce individual transducers or heads which are used

-2-

to form sliders. These sliders are used to read back and/or write information onto a surface of a magnetic disc, for example, which moves at a high rate of rotation.

5 In order to establish adequate performance for high efficiency recording heads, it is necessary to achieve the desired stripe height or throat height. There are many factors which affect variations in the ultimate stripe height or throat height. These factors
10 include variations in the position and size of elements induced during wafer processing. The step of slicing the substrate into bars can also introduce variations. Mounting induced thermal stress can also cause variations during the processing of the wafers into
15 sliders. Further, the profile of the lapping surface can lead to variations.

Electrical lapping guides (ELGs) are sensors which are deposited onto the wafer during the fabrication process. The output from the ELGs can be
20 used to determine when to stop the lapping process. Typically, the ELGs are fabricated along with the transducers using the same wafer processing steps. This is described, for example, in U.S. Patent No. 4,477,968 which issued October 23, 1984 and U.S. Patent No.
25 4,559,743 which issued December 24, 1985.

Lapping generally refers to machining processes in which material is very slowly, at a controllable rate, removed from a surface. Typically, the process involved applying a work surface of the work
30 piece to a moving surface which is slightly abrasive. One such device is described in U.S. Patent No. 4,536,992 which issued August 27, 1985. Thus, by controlling the lapping process in response to the output from the ELGs, a closed loop machining process is

-3-

set up in which the output from the ELGs are used as feedback to the lapping machine.

During the lapping process, the slider is held on a carrier which attaches to the arm of the lapping apparatus. Such a carrier is described in U.S. Patent No. 4,457,114 which issued July 3, 1984. The carrier in U.S. Patent No. 4,457,114 uses two actuators to bend the bar during the lapping process. In U.S. Patent No. 4,457,114, the carrier provides bending of the bar at both ends around the center of the bar. This bending is used to provide non-uniform removal of material from the bar in order to compensate for variations in the bar and the throat height or stripe height of the sensor. In U.S. Patent No. 4,457,114, the actuators comprise pins which are heated to thereby expand and apply a force to the bar which bends the bar. A variation on this technique is to use three different actuators to apply force to a bar at three different points.

Generally, the prior art has focused on improved ELGs and lapping mechanisms. However, as the data storage industry is continuously driven to higher and higher densities and in an ongoing effort to reduce costs of fabrication, a number of competing factors are observed. First, the sensor height tolerance requirement is getting smaller. Second, the density of heads carried on each bar is getting larger. Third, the aspect ratio of the length to the thickness of each bar is getting larger. Therefore, existing lapping and bending systems are often inadequate for controlling the lapping process. These factors not only lead to heads which are more sensitive to processing induced disturbances, but also lead to bars which are more easily disturbed because they are thinner and the

-4-

stiffness of the bar is related to the cube of its thickness.

SUMMARY OF THE INVENTION

The present invention includes a lapping apparatus which provides improved control during the lapping process. In one embodiment, a device for lapping a bar which carries a plurality of sliders includes a first actuator adapted to couple to the bar and to impart a first controllable force in response to a first control signal and a second actuator adapted to couple to the bar and impart a second controllable force in response to a second control signal. An arm of the device couples to the bar through the actuators and applies a lapping force to the bar and against the lapping surface. A controller provides first and second control signals to the first and second actuators, respectively, to thereby impart a plurality of forces on the bar. The forces are selected to obtain a desired profile of the bar and to obtain a desired distribution of the lapping surface across the profile of the bar.

In one embodiment, seven different actuators are used to provide seven separate control points for bending of the bar.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of a head carrying bar of the type used in the present invention.

Figure 2 is a simplified schematic diagram of a prior art carrier having two actuated points and a fixed point.

Figure 3 is a simplified schematic diagram of a prior art carrier having three actuated control points and two fixed control points.

-5-

Figure 4 is a simplified schematic diagram showing a carrier in accordance with one embodiment of the present invention.

5 Figure 5 is a graph showing deflection for the carrier of Figure 3 and the carrier of Figure 4.

Figure 6A is a front plan view and Figure 6B is a top perspective view, respectively, of a carrier in accordance with one embodiment of the invention having nine control points.

10 Figure 7 is a graph showing deflection versus position of a carrier in accordance with the present invention having a single control point actuated.

Figure 8 is a simplified diagram of a lapping system in accordance with the present invention.

15 Figure 9 is a front plan view of a carrier in accordance with another embodiment having seven adjacent actuated control points and fixed control points on either end of a profile of the carrier.

Figure 10 is a front plan view of a carrier in accordance with another embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides a method and apparatus for accurately lapping a bar carrying a plurality of heads of the type used to write and/or read back information from the surface of a magnetic storage disc. Figure 1 is a perspective view of bar 10 which carries a plurality of heads 12. The dimensions of head 12 are significant and it has been known to use a lapping process to obtain the desired dimensions. As described in the Background section, lapping is a controlled material removal process in which a work surface of bar 10 is pressed against a moving, abrasive surface to thereby selectively and controllably remove material from bar 10. This lapping is performed using

-6-

a lapping machine which includes an arm, a lapping surface and a carrier which couples bar 10 to the arm. The arm presses the bar against the lapping surface to thereby cause material to be removed from bar 10.

5 It has been known in the prior art to control the profile of the carrier. This control is used to more accurately control the material removal. Specifically, as illustrated by Figure 1, bar 10 is an elongated element which may bend or have deformities.
10 By controlling the profile of carrier used to hold bar 10 during lapping, it is possible to compensate for these bends or deformations.

Figure 2 is a simplified schematic diagram of a prior art carrier 14 having profile 16. In Figure 2,
15 fulcrum 18 represents a fixed portion of carrier 14 and bi-directional arrows 20 and 22 represent actuators at either end of profile 16. Profile 16 is adapted to couple to a bar, such as bar 10. Figure 2 is similar to the carrier described in U.S. Patent No. 4,457,114,
20 issued July 3, 1984. Thus, carrier 14 provides limited control of profile 16 such that variations in bar 10 can be compensated. Figure 3 is a simplified schematic diagram of another prior art carrier 30. Carrier 30 has a carrier profile 32 which is coupled to fixed control
25 points or fulcrums 34 and 36 and actuators which control actuated control points represented by bi-directional arrows 38, 40 and 42.

One aspect of the present invention includes the recognition that there are two parameters which must
30 be controlled during lapping. These parameters are bending of the bar profile and balancing of the force applied to the bar. Bending of the bar refers to adjusting the profile of the bar such that the bar becomes relatively straight (or is otherwise shaped as

-7-

desired). Balancing, on the other hand, is the distribution of pressure across the bar. For example, in the prior art design of Figure 3, balancing is determined by the relative positions of fulcrums 34 and 36. The actuators represented by arrows 38, 40 and 42 are used to control the shape of the bar profile.

Another aspect of the present invention includes the recognition that the use of additional control points on a carrier can be used to provide more accurate control of a bar during a lapping process. The present invention includes determination of the number of control points needed to achieve a desired degree of control for a bar having a desired length. For example, given a bar profile for I bars defined by J data points, x_{ij} , y_{ij} where $i = 1, 2, \dots, I$, and $j = 1, 2, \dots, J$. A polynomial curve fit function is formed using a least squares fit analysis:

$$\bar{y}_{ij} = f(a_1, a_2, \dots, a_k, x_{ij}) \quad \text{Eq. 1}$$

where k equals 2, 3, . . . and is the order of the curve and $a_1, a_2, \dots$ are the coefficients of the curve. Next, the root mean square (RMS) of the residuals for each k are calculated according to the following formula:

$$RMS_k = \sqrt{\frac{1}{IJ-1} \sum_{i,j} (y_{ij} - \bar{y}_{ij})^2} \quad \text{Eq. 2}$$

Using Equation 2, the number of control points (k) required to achieve the desired amount of control can be determined by assuming that a $(k-1)^{\text{th}}$ order curve can be bent straight and setting RMS_k to the desired minimum variation in the bar profile. One can then calculate the necessary order of the RMS curve fit which also

-8-

provides the number of control points. For example, if RMS_k is less than 1 μ inch Equation 2 is solved with k equal to 10. This analysis has been verified experimentally using carriers having five control points over a 2 inch long bar and five control points over a 1 inch long bar. The standard deviation of the 2 inch long bar was 2.3 μ inch while the standard deviation of the 1 inch long bar was 0.78 μ inches. This leads to the conclusion that nine control points is sufficient to obtain a variation of less than 1 μ inch in the finished bar profile for a standard 2 inch long bar. Table 1 shows that between 9 and 10 control points are needed to achieve control to within 1 μ inch in a 2 inch bar.

Curve Fit Parameter #	RMS of residuals between individual point and curve on each bar				RMS over 15x24 points	STDmeasure =1.67 μ inch
	mean	median	75%	90%		
2	39.32	33.44	60.28	72.85	46.67	46.64
3	19.87	13.59	27.57	46.91	25.13	25.07
4	8.96	6.54	10.96	18.78	11.4	11.28
5	6.06	4.48	6.54	9.63	7.5	7.31
6	4.67	3.39	5.77	8.63	5.6	5.35
7	3.21	2.57	3.82	7.26	3.62	3.21
8	2.56	2.23	2.97	4.66	2.82	2.27
9	2.09	2.02	2.61	2.98	2.19	1.42
10	1.69	1.62	2.01	2.78	1.74	0.49

TABLE 1

Figure 4 is a simplified schematic diagram of a carrier 50 in accordance with one embodiment of the present invention. Carrier 50 is shown with profile 52 having control points A, B, C, D, E, F, G, H and I. Control points A, B, D, E, F, H and I are coupled to actuators (not shown in Figure 4) while control points C and G are stationary fulcrums 54 and 56, respectively. In Figure 4, control point A is shown actuated a distance of U_1 , control point B is shown actuated distance U_2 , control point D is shown actuated distance

-9-

U₃, control point E is shown actuated distance U₄, control point F is shown actuated a distance U₅, control point H is shown actuated a distance U₆ and control point I is shown actuated a distance U₇. Thus, there are nine separate control points shown in Figure 4 of which seven are individually actuated and two are fixed. This provides eight different segments to profile 52 which can be controlled, segments A-B, B-C, C-D, D-E, E-F, F-G, G-H and H-I. The slope θ of a line passing through control points C and G can be used to control balance of carrier 50 and the distribution of the lapping force across profile 52. During operation, the actuators which couple to points A, B, D, E, F, H and I are preferably controlled such that profile 50 is a substantially straight line.

Figure 5 is a comparison of deflection using a prior art three-point bending carrier such as shown in Figure 3 and a seven-point bending carrier such as shown in Figure 4. Figure 5 is a graph showing the average difference between a deformed carrier shape and a bar bow at various positions along the length of the bar. Line 60 is for a three-point carrier and line 62 is for a seven-point carrier. The graph of Figure 5 was calculated using a finite element method (FEM) modeling technique. As shown in Figure 5, the three-point bending allows substantial variation to the profile, particularly between the end point actuators (i.e., between 34 and 38 and between 36 and 42 shown in Figure 3.)

Figure 6A is a front plan view and Figure 6B is a top perspective view of carrier 50 in accordance with one embodiment of the present invention. Carrier 50 includes main body 70 having detents 72 formed therein and presenting carrier profile 52. Profile 52

-10-

includes control points A-I. Nine control areas 74, 76, 78, 80, 82, 84, 86, 88 and 90 are formed in main body 70 adjacent control points A-I, respectively. Control areas 74-90 are defined by regions of reduced strength in main body 70 formed by cutouts 92, 94, 96, 98, 100, 102, 104, 106, 108 and 110. Further, plate spring cutouts 112, 114 and 116 are positioned parallel to and opposite profile 52. Actuator couplings 120, 122, 124, 126, 128, 130 and 132 are positioned within control areas 74, 76, 80, 82, 84, 88 and 90, respectively. Main body 70 may also optionally carry bar code information 140. The design of carrier 50 in Figures 6A and 6B is selected based upon the design goal of balancing structure bending stiffness while achieving the desired bar bow correction requirements based upon available bending capacity (load and travel) of the actuators.

In operation, actuators (not shown in Figures 6A and 6B) are adapted to couple to actuator couplings 120-132 to control the profile 52 as desired. Using control area 74 as an example, cutouts 92 and 94 allow vertical movement which is transferred to control point A. Furthermore, control area 78 controls control point C. The cutout portions 92-110 have a shape selected to reduce the coupling to adjacent control areas. However, control area 78 is more closely coupled to main body 70 because of the spacing between parallel spring cutouts 112 and 114. This is also true for control area 86 with respect to cutouts 114 and 116. Thus, control areas 78 and 86 provide stationary control points or fulcrums 54 and 56, respectively, shown in Figure 4. Another aspect of the present invention is the vertical offset between adjacent actuator couplings 120 and 122, for example. This offset allows the actuator couplings to be more closely spaced thus allowing additional control points

-11-

and therefore greater control. Further, cutouts 96 and 104 are staggered to further improve spacing. Plate spring cutouts 112, 114 and 116 provide a plate spring parallel mechanism which yields more linear bending on the bar and reduces off-plane displacement due to the lapping force or an off center bending force. Cutouts 112, 114 and 116 reduce the amount of twisting motion which could be imparted to profile 52 due to the lapping force of the lapping surface as it is moved past profile 52.

Another aspect of the present invention includes the use non-uniform spacing between control points in order to improve control or more evenly distribute control. For example, referring back to Figure 5, the deflection between the two end points in graph 62 indicates that the maximum variation occurs between points A and B and points H and I. Therefore, rather than uniformly distributing the control points, the design of Figures 6A and 6B has reduced spacing between side control points (i.e., sections A-B, B-C, G-H and H-I) than that of the middle control points (i.e., sections C-D, D-E, E-F and F-G). This spacing may be adjusted as appropriate to achieve either a uniform distribution or any desired distribution. Detents 72 are used to clamp carrier 50 to the arm of the lapping device. Registration sections 142 provide a reference surface for the lapping arm during the lapping process. In one preferred embodiment, carrier 50 is formed of white TZP Zirconia ceramic which allows for easy maintenance. The bar code 140 can be used to track carrier 50 and/or an associated bar carried on profile 52 during the machining process.

One aspect of the present invention includes characterizing the carrier for subsequent use during the

-12-

lapping process. Figure 7 is a graph based upon FEM modeling which shows the response of profile 52 when point D is actuated through actuator coupling 124. Figure 7 is a graph of deflection versus bar length.

5 Figure 7 shows that the individual bending control points are closely coupled together in the present invention. Note that this is in contrast to the prior art designs shown in Figures 2 and 3 in which the points are spaced further apart and each actuated control point

10 is separated by a fixed control point. Thus, in the present invention, the movement of a single control point significantly alters the entire profile of the carrier. Therefore, in order to actively control the bending of the bar during the lapping process, an

15 accurate transfer function must be determined which describes the carrier response to different loading situations. This transfer function may be defined as a matrix. Assume that:

20 $\bar{F} = [F_1, F_2, \dots, F_7]$ is the applied bending forces on the carrier 50 at each control point, and

$\bar{U} = [U_1, U_2, \dots, U_7]$ is the resulting displacement of profile 52 for each of the control points A-I, respectively.

A sensitivity matrix $\bar{K}$ can be generated according to the

25 formula:

$$\bar{K} \cdot \bar{F} = \bar{U} \quad \text{Eq. 3}$$

where:

-13-

$$\bar{K} = \begin{bmatrix} k_{11} & k_{12} & k_{13} & & & & k_{17} \\ k_{21} & k_{22} & & & & & k_{27} \\ k_{31} & & & & & & \\ & & & \dots & & & \\ & & & & & & \\ & & & & & & \\ k_{71} & k_{72} & & & & & k_{77} \end{bmatrix}$$

The sensitivity matrix $\bar{K}$ defines the behavior of profile 52 in response to forces applied at each of the actuator coupling points 120-132. The major diagonal components in $\bar{K}$ describe the direct effect of forces applied at individual bending points. The off-diagonal components in $\bar{K}$ describe the coupling effect between the various points.

The sensitivity matrix $\bar{K}$ can be established by quantifying the carrier displacement response to individually applied known bending forces. This may be performed either through actual experimental measurements or using FEM modeling techniques. During the lapping process, the equation is solved in reverse. First, the normalized bar bow profile is formed using ELG feedback information. The profile of the bar is leveled using balancing of the fixed control points. The carrier deflection required to bend the bar straight is calculated in accordance with the equation:

$$\bar{U} = [U_1, U_2, \dots, U_7] \quad \text{Eq. 5}$$

Where U_1 - U_7 represent a flat profile. Next, equation 3 is solved for $\bar{F}$:

$$\bar{F} = [F_1, F_2, \dots, F_7] \quad \text{Eq. 6}$$

Where F_1 - F_7 are the forces which must be applied by each actuator to achieve the desired profile described by $\bar{U}$.

Figure 8 is a simplified diagram showing a lapping system 98 in accordance with the present

-14-

invention. Lapping system 198 includes armature 200 having clamps 202 which are adapted to clamp to carrier 50 at detents 72. Armature 200 is carried on elongated arm 204 which couples to fulcrum 206. Armature 200 is positioned whereby bar 10 which couples to carrier 50 is in contact with a lapping surface 208. Armature 200 carries actuators 220, 222, 224, 226, 228, 230 and 232 which couples to couplings 220-232 through actuator armatures 240, 242, 244, 246, 248, 250 and 252, respectively. Actuators 220-232 receive control signals through control lines 260₁₋₇ from control system 262. Armature 200 also couples to balancing actuator 264 which is positioned opposite carrier 50 relative to fulcrum 206. Actuator 264 also couples to control system 262. A feedback connection 266 is provided from electronic lapping guides (ELGs) carried on bar 10. Control system 262 includes a user input 270, such as a keypad, a user output 272, such as an LED display, memory 274, ELG input 276 a controller 278, such as a microprocessor, and an actuator driver.

In operation, the lapping process is controlled by control system 262. Controller 278 retrieves instructions and parameters from memory 274. For example, the matrix of Equation 4 may be stored in memory 274. Instructions and information are received from user input 270 and the status of the lapping process may be displayed on display 272. Additionally, lapping system 198 may include a bar code reader (not shown) to read bar code information 140 for use by controller 278. Feedback regarding the progress of the lapping operation is received through ELG input 276 and provided to controller 278. Controller 278 solves Equation 3 for $\bar{F}$ and responsively controls actuators 220-232 and 264 using driver 280. Driver 280 may

-15-

comprise, for example, a transistor circuit providing a power output to actuate the actuators. Actuators 220-232 and 264 may be any appropriate actuator which is capable of providing a controlled movement such as a hydraulic system, a voice coil, a pneumatic actuator, a piezo electric system, thermal, magnetostrictive, etc. Those skilled in the art will recognize that the present invention is not limited to any particular actuator. Actuator 264 is used to provide a balance control to balance distribution of the force applied to bar 10. Actuators 220-232 are used to apply the individual forces of vector $\bar{F}$. The total amount of force applied on bar 10 may be controlled by a weight or another actuator (not shown). As shown in Figure 8, lapping system 198 provides a closed loop in which the output from the ELG sensors are used as feedback by controller 278 to control actuators 220-232 and 264. Lapping surface 208 may comprise, for example, a rotating disc. The lapping system of Figure 8 is provided as an example only and the carrier of the present invention may be employed with lapping systems of any appropriate design.

Figure 9 is a plan view of a carrier 300 in accordance with another embodiment. Carrier 300 provides control points 302, 304, 306, 308, 310, 312, 314, 316 and 318 along profile 320. Carrier 300 is an example of a carrier in accordance with the present invention in which end points 302 and 318 are fixed while control points 304-316 are all individually actuated. Note that this also uses a single cutout 322 to provide the parallel spring mechanism.

It will be understood that any appropriate orientation of cutouts or other mechanisms to allow relative movement of the control points is within the scope of the present invention. Figure 10 shows a plan

-16-

view of a carrier 340 which illustrates another technique for selecting the shape of cutouts in the carrier body. The cutouts in carrier 340 are designed to reduce deflection of the carrier profile due to lapping pressure. Carrier 340 accomplishes this goal by contouring the beam of the cutout. Additionally, the thickness of carrier 340 can be increased to further reduce lapping induced deflection.

The present invention provides a lapping system having a carrier which allows improved control of the bending of a bar during a lapping process. The present invention includes numerous features including an increased number of actuators and closer spacing between actuators. Further, in contrast to prior art designs, in the present invention actuators are placed adjacent one another without an intermediate fixed region. Further, in the present invention, the actuator mechanism is placed on the arm of the lapping machine such that the mechanism need not be placed on each bar. Attachment of the bar to the carrier may be through any appropriate technique. In one embodiment, the bar may be slid into a slot carried on the profile of the carrier. Further, the actuators of the present invention may be used to either push or pull the bar and thereby allow deformations in either direction. Preferably, bending of the bar is centered around the normal profile of the bar. This reduces any extra bending stress placed on the bar during lapping. In one preferred embodiment, the lapping of a 2 inch long bar is controlled to within a standard deviation of less than 1 μ inch using a minimum of nine separate control points, seven for bending and two for balancing the lapping force. This number may be increased or decreased as appropriate based upon the length of the

-17-

bar and the desired minimum standard deviation. Clamping of the carrier may be through any appropriate technique and is not limited to the specific clamps described herein. Further, the actuators may be coupled
5 to the carrier using other techniques. As used herein, the term "control point" may be either a fixed control point (shown as a fulcrum in the schematic drawings) or an actuated control point.

Although the present invention has been
10 described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. For example, any number of control points, formed by any appropriate
15 technique, in any type of carrier, actuated or fixed by any means may be used. Further, any type of lapping may be used, and the arm can be integral with the carrier. The control points could also be formed integral with the bar itself. This might require additional
20 connections to the bar.



-18-

WHAT IS CLAIMED IS:

1. A device for lapping a bar carrying a plurality of sliders, comprising:

a first actuator adapted to couple to the bar and impart a first controllable force in response to first control signal;

a second actuator adapted to couple to the bar and impart a second controllable force in response to a second control signal;

a lapping surface;

an arm coupled to the first and second actuators which provides a lapping force to the bar against the lapping surface; and

a controller providing the first and second control signals to the first and second actuators, respectively, to impart a plurality of forces on the bar selected to obtain a desired profile of the bar and to obtain a desired distribution of the lapping force across the profile of the bar, wherein bending caused by the first actuator interferes with bending caused by the second actuator and the control signal is selected as a function of the interference.

2. The device of claim 1 wherein the controller includes memory which contains a sensitivity matrix describing a relationship between the interference between the first and second actuators and the control signal is selected as a further function of the sensitivity matrix.

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED



-19-

3. The device of claim 1 including a carrier coupling the arm to the bar and including a first control point coupled to the first actuator and a second control point coupled to the second actuator.

4. The device of claim 3 including a balancing actuator coupled to the controller and wherein the carrier includes at least two fixed control points coupled to the balancing actuator to apply a balancing force to the bar.

5. The device of claim 4 wherein the carrier includes a third control point coupled to a third actuator and a fourth control point coupled to a second actuator and wherein the two fixed control points are separated by at least two control points.

6. The device of claim 3 wherein the carrier includes a first control area for coupling to the first actuator and transferring force to the first control point, the first control area defined by a region of reduced strength in the carrier.

7. The device of claim 3 wherein the carrier includes a third control point and spacing between any pair of adjacent control points is non-uniform.

8. A device for lapping a bar carrying a plurality of sliders comprising:

an arm;

a lapping surface;

a first actuator coupled to the arm;

a second actuator coupled to the arm;

a carrier comprising:

a work surface adapted to couple to the bar and press the bar against the lapping surface;

a first control point on the work surface coupled to the first

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED



-20-

actuator and positioned to apply a first force to the bar; and

a second control point on the work surface adjacent the first control point coupled to the second actuator and positioned to apply a second force to the bar;

wherein the first and second control points are positioned such that displacement of the first control point causes displacement of the second control point.

9. The device of claim 8 including a controller coupled to the first and second actuators providing control signals to the first and second actuators as a function of a sensitivity matrix which describes a relationship between movement of the first actuator and a resulting movement of the second control point.

10. The device of claim 8 wherein the carrier further comprises first and second fixed control points which control balancing of the bar relative to the lapping surface.

11. The device of claim 10 wherein the carrier further includes third and fourth control points on the work surface and wherein the two fixed control points are separated by at least two control points.

12. The device of claim 8 wherein the carrier includes a first control area coupling to the first actuator and transferring movement to the first control point, the first control area defined by a region of reduced strength in the carrier.

13. The device of claim 8 wherein the carrier includes a third control point and spacing between any pair of adjacent control points is non-uniform.

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED



-21-

14. A device for lapping a bar carrying a plurality of sliders, comprising:

an arm;

a lapping surface;

a carrier comprising:

a work surface adapted to couple to the bar and press the bar against the lapping surface; and

first, second and third adjacent control points coupled to the arm and to the work surface;

wherein spacing between the first and second control point is different than spacing between the second and third control points.

15. The device of claim 14, the carrier further comprises a fourth control point and wherein the first and fourth control points are fixed control points and are separated by the second and third control points.

16. The device of claim 14 including a first control area adapted to transfer movement to the first control point, the first control area defined by a region of reduced strength in the carrier.

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED