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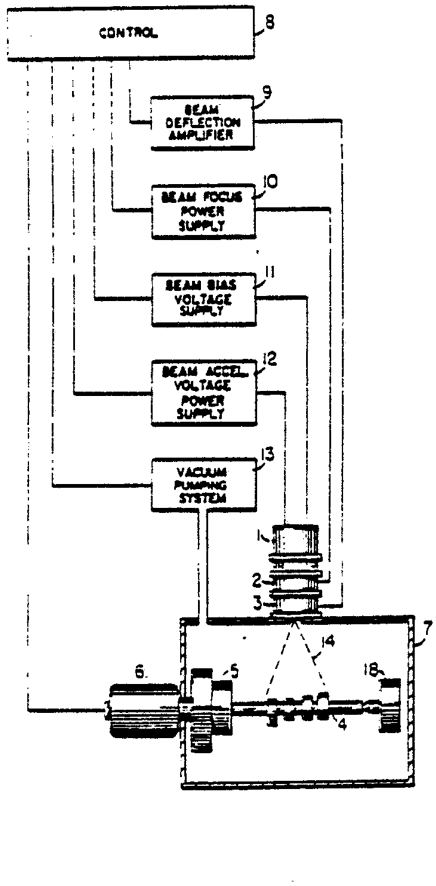
(54) **Title:** METHOD AND APPARATUS FOR SURFACE HARDENING CAMS

(57) Abstract

Method and apparatus for simultaneously surface heat treating the wear surfaces of a multiplicity of cams (24-27) on a camshaft (4) by transferring to the cam surfaces the energy of a concentrated beam (14) of electrons. The electron beam (14) is directed for a predetermined time to a desired spot on the surface of the said cams (24-27) and is caused to move incrementally from one to the next of a predetermined matrix of spots (28-31) on the work surface as the camshaft (4) is being rotated. After the predetermined matrix pattern (28-31) has been repeated one or more times, the beam (14) is then directed sequentially from one cam (24) to the next (25) and the process repeated until all wear surfaces on the cams have been treated. The predetermined pattern (28-31) is projected over the desired surface of all the cams (24-27) a predetermined number of times so that the material to be heat treated at the intersection of the plane described by the beams's motion and all the cam surfaces being, in effect, simultaneously heat treated is brought above the transformation temperature by close control of the electron beam (14) parameters. The beam power and dwell time of the beam at each point are programmed in accordance with the linear velocity of the particular cam surface being instantaneously treated in such a way that the instantaneous energy per increment of surface of each of the cams is made to follow a predetermined law of instantaneous energy input vs. angular position of the cam. Each heat element along the surface of the cam as it moves from under the beam is rapidly cooled by the underlying mass of cold material to effect a quench.



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Description

Method and Apparatus for Surface Hardening Cams

Technical Field

This invention relates to a method and apparatus for simultaneously heat treating several cams formed on a cam shaft similar to those utilized on internal combustion engines.

The heat treatment of metals is an important industrial process which is utilized to impart to the metal desirable properties, such as toughness or hardness. For some applications, where steels are used for tools for working metals, it is necessary that the material be hardened to as great a depth as possible so that the tool retains its cutting properties so that it may be ground periodically as it wears. Steel at room temperature consists of two phases:

(1) Ferrite, which is essentially iron that has very small amounts of dissolved carbon and alloying elements, and;

(2) Carbides, which are composed mainly of alloying elements and carbon.

To be hardened, the steel must be heated above a certain temperature, where the ferrite transforms to another structure called austenite. The quantity of carbon which the austenite is capable of accepting depends on the temperature, and this quantity decreases as the temperature is lowered. If the austenite is quenched at a sufficiently rapid rate, the carbon is not able to precipitate out of solution and remains trapped in the structure. The trapped carbon produces a super-saturated solution in ferrite, which is called martensite. It is the capacity of the steel to keep the carbon in solution and undergo the martensitic transformation which is the important factor in hardening. There is a great variety of carbon tool steels and alloy steels each of which when subjected to the proper heat treatment, results in a product having the desired characteristics for each specific application.

Whereas tools for metalworking require hardness throughout the material, there are many industrial parts which require a hard, wear-resistant surface and a ductile or tough core. Surfaces of such parts are hardened by carburizing, nitriding, cyaniding, or carbo-nitriding.

Background Art

Carburizing requires that the parts be exposed to a carburizing gas at elevated temperatures for periods of about 5 to 72 hours or packed in a carburizing compound for this period. Carbon monoxide or methane is the carrier gas, and carbon dissolves in the austenite and penetrates below the surface by diffusion.

In nitriding, the parts are heated in an ammonia atmosphere at 450 to 540 degrees centigrade (850 to 1,000 degrees Fahrenheit) for about 8 to 96 hours. The material is hardened to a depth of 0.025 inches.

In the carbo-nitriding process, the parts are subjected to a gaseous atmosphere containing hydrocarbons and ammonia at a temperature of 650 to 900 degrees centigrade.

Another process by which steel parts may be hardened is the induction heating process. The parts are held adjacent to, or within, a coil through which alternating current passes. High frequencies are used for small parts or for surface heating and low frenquencies are utilized for heating in-depth.

The carburizing, nitriding, and cyaniding processes are awkward to apply and are time-consuming. Hardening by the use of the induction heating process requires somewhat less time and may be done on a production line basis, but requires the use of specially shaped coils for each application.

Aside from the danger in working with noxious and poisonous gases and liquids and the production of air pollutants formed during the hardening process, all the above processes suffer from the inconvenience resulting from the parts being hardened becoming distorted because they are subjected to high temperatures for long periods of time. If the parts become distorted, it becomes necessary to rework them by remachining them to the required tolerance - a costly procedure made more costly because the parts are then in the hardened state.

Disclosure of Invention

The present invention is directed to the local surface heat treatment of camshafts at extremely high speeds and is useful in overcoming the deficiencies in the above heretofore used methods of heat treating. The new heat treating process utilizes the high-power density available in the electron beam which is generated by accelerating a beam of electrons by a high-potential, electrostatic field and directing the electron beam by focusing and deflecting it along two mutually perpendicular axes so that the beam is played upon the work in a desired, two-dimensional pattern as the camshaft is rotated at a predetermined, angular velocity, about its longitudinal axis. In this manner, each of the wear surfaces of all the cams on the camshaft may be simultaneously heat treated without it being necessary to bring the total mass of the camshaft to the proper heat treating temperature. Because of this, the total energy required by this new process is only a fraction of the energy which must be utilized in the older processes for heat treating camshafts. With this process, the surfaces on the periphery of each of the cams on the camshaft are rapidly brought to a temperature just below the melting point at the points where the beam is being applied as the camshaft is being rotated. As each incremental surface is rotated away from the beam impingement zone, that surface is self-quenched by the surrounding mass of cold metal in the part. There is no need for a quenching medium, such as a water spray or an oil bath. During the heat treating process, the electron beam is deflected in accordance with a predetermined program of position and dwell time under control of a device which has been programmed to control the deflection coils of the electron gun along two axes so that the beam is stepped instantaneously from one point to the next in a predetermined pattern. The beam remains fixed at each point for a predetermined interval of time so as to produce a pattern of spots of heat over each of the surfaces being heat treated effectively simultaneously. The concentration of spots may be varied, the beam power may be varied, and/or the dwell time at each point may be varied from area to area being heat treated. It is the object of this invention to make possible the heat treatment of camshafts bearing a multiplicity of cams with the least expenditure of energy and time.

Another object of the invention is to produce a rapid rise in surface temperature over a multiplicity of localized areas of a work piece.

Another object is to produce a multiplicity of patterns of electron beam impingement points over localized areas of a work piece in which the concentration of spots per unit area varies over the surface being heated.

Another object is to provide means for surface heat treating a multiplicity of areas on the surface of an object by generating an electron beam and controlling the electron beam current, voltage, focus, and dynamic application of the beam over the separate areas to be heat treated simultaneously.

Another object of the invention is to simultaneously surface harden the wear surfaces of a multiplicity of cams formed in a common camshaft.

Another object is to provide a method whereby the wear surfaces of a multiplicity of cams on a camshaft which has been machined to its final dimensions may be surface hardened with no appreciable distortion resulting in the work piece due to the hardening process.

Brief Description of Drawings

These and other objects and advantages will become more apparent in view of the following detailed description taken in conjunction with the drawings described below:

Figure 1 - is a block diagram showing the essential elements of the apparatus in accordance with this invention.

Figure 2 - is a schematic drawing of the essential elements of an electron beam gun and its power supply.

Figure 3 - is a front view of a typical camshaft having a multiplicity of cams.

Figure 4 - is an end view of the camshaft illustrated in Figure 3.

Figure 5 - is an illustration of the shape of a typical cam about its axis of revolution.

Figure 6 - is a perspective drawing of a camshaft showing the general motion of the beam as applied to a group of four cams on a single shaft.

Figure 7 - shows a pattern of point array for heat treating four cam surfaces simultaneously.

Figure 8 - shows the macro structure of a section of one of the cams shown in Figure 6 after heat treatment by the electron beam.

Best Mode for Carrying Out the Invention

Referring now to Figure 1, which illustrates the complete system for the surface heat treatment by an electron beam of a camshaft bearing a multiplicity of cam lobes, we may note the electron beam gun (1) fitted with a focus coil (2) for focusing the electron beam on the work and deflection coils (3) for deflecting the beam along two mutually perpendicular axes so that the beam may strike each of the cam lobes to be surface heat treated in accordance with a predetermined program applied through the control (8). The camshaft (4) is supported between the tail stock (18) and the head stock (5) within a vacuum chamber (7), which is maintained at a low pressure suitable for the electron beam heat treating process by vacuum pumping system (13). The head stock is driven by the motor (6), whose speed may be regulated and programmed by well-known means provided in control (8). Means are provided in association with the head stock for identifying continuously the angular position of the camshaft with respect to a given reference axis. The overall control, which may be effected by either a computer, a programmable control or a system of logic elements, in conjunction with suitable input and output means, is utilized to control the various parameters of the electron beam system, such as filament current, beam acceleration voltage, focus current, beam deflection, and beam bias (beam current), as well as the overall control and monitoring of the vacuum pumping system and the motor control. In order to heat treat a cam, the operator fastens the camshaft between head stock and tail stock mounted within the vacuum chamber, closes the door of the vacuum chamber, and initiates the functioning of the machine by pressing a start button. The control will then take over the operation, following a preset program which has been established for the operation of the vacuum system to evacuate the chamber to the desired pressure, after which the electron beam gun is automatically energized and the beam controlled so that the desired heat treat pattern of beam displacement and beam dwell time is projected repetitively while the camshaft is rotated at a predetermined angular velocity. The deflection coil assembly (3) is utilized to deflect the electron beam passing through it along two mutually perpendicular axes, and a timing device within the control, acting in conjunction with the deflection means, determines the dwell time of the beam at each predetermined point in the preset pattern of points. For example, the control may be programmed to form a symmetrical 11 x 11 matrix of 121 point locations to which the beam will be directed in sequence for a predetermined period of time to the surface of a portion of the cam surface to be hardened. The deflection coils are so controlled that this matrix is repeated at a preset rate; for example, 100 matrices (or frames) per second.

Figure 2 illustrates in schematic form the general arrangement of the principal elements of an electron beam gun and its associated electrical supplies. The elements of an electron beam gun system comprise a filament (15), a cathode (16), an anode (17), a focus coil (2), deflection coils (3), and their associated supplies (20), (21), and (23). Filament current supply (2) delivers current to filament (15) and brings the temperature of the filament to the level at which it is in condition to deliver electrons. A high-voltage power supply (22) applies a potential of 60,000 volts to anode (17) with respect to filament (15) to cause the electrons to be accelerated towards the anode and through an aperture in the anode so as to form a beam of electrons moving at a velocity which may approach the speed of light. The cathode (16) and anode (17) are shaped in such a manner as to create an electrostatic field between the anode and the cathode which causes the electron beam to be directed towards a point a short distance outside of the anode. An adjustable DC power supply (21) of approximately 2,000 volts is applied between the filament and the cathode and by this means, the intensity of the electron beam current may be controlled. Increasing the negative potential on the cathode with respect to the filament reduces the electron beam current and vice versa. Beyond the opening in the anode there exists a field free space through which the beam passes through the focus coil (2) where it is focused to a desired spot on a work piece by adjusting the focus current applied to the focus coil by power supply (23). Directly below the focus coil, the deflection coils (3), energized by electrical currents delivered to the coils (3) from the beam deflection amplifiers (9) under control from signals received from a computer or other type of control (8), cause the beam to impinge at a desired point upon the work. The output of all the various current and voltage supplies for the electron beam gun may be controlled and all may be programmed so that these values may be modified and varied during the generation of the points in the matrix or varied for each complete matrix. For example, each successive matrix may be made to differ in beam current during the passage of a series of matrices so as to produce the desired heating effect upon the work piece.

The matrix of Figure 7 represents the points to which the beam is displaced in accordance with a predetermined sequence which is utilized in the simultaneous heat treatment of four separate cam lobes formed on a single camshaft. This matrix may be displayed upon the screen of a cathode ray oscilloscope for use in setting up and monitoring the heat treat operation. The position of each spot will then be shown on the cathode ray oscilloscope screen, and the brightness of the spots on the screen will indicate the relative length of time the beam remains at any particular spot. Brighter spots indicate longer beam duration.

In the surface heat treatment of a single cam periphery, as illustrated, for example, in Figure 5, it has been found that a uniform heat treatment of the periphery can be obtained by applying the electron beam in a repetitive matrix of a given number of points to a well-defined section of the periphery of the cam if the power density in the beam is continuously adjusted so that the energy applied per unit surface is maintained substantially constant, although the beam strikes the work surface at differing angles as the cam is rotated. For example, with the beam being applied from the top, as shown, it will be normal to the surface of the cam from approximately 180^{o} to slightly more than 360^{o}. From 0^{o} to 90^{o}, the beam will not be normal to the surface, and the portion of the surface which is struck by the matrix will be greater than the surface struck by the matrix as the cam traverses from 180^{o} to 360^{o}. At 90^{o}, the beam will again be normal to the surface, and from 90^{o} to 180^{o}, the area upon which the matrix impinges will again vary and increase in proportion to the reciprocal of the sine of the acute angle between the axis of the beam and the tangent to the surface upon which the beam is impinging. In order to maintain a constant value of energy input per unit surface over the periphery of the cam surface as the cam rotates at a fixed angular velocity, it is necessary to control the average power of a matrix element in proportion to the product of the angular velocity of the cam, the cam radius at the point of impingement of the beam, and the co-secant squared of the angle between the tangent to the cam surface and the cam radius at the point of impingement of the beam.

The present invention is directed to the process whereby a multiplicity of cams on one cam shaft in which the high points on each of the cams are disposed about the camshaft at different angular positions may be simultaneously heat treated by a single electron beam generated in a single electron beam gun. Heretofore, one could readily concede that this could be done through the use of four electron beam guns, each electron beam gun directing its electron beam to the surface to be heat treated on a separate cam. The present invention utilizes but a single gun in a time-sharing process to heat treat a multiplicity of cams simultaneously.

Figure 3 illustrates a section of a camshaft (4) bearing four lobes (24), (25), (26), and (27). In this particular arrangement, all of the cams are identical in shape, but each is displaced about the shaft (4) in accordance with the required angular displacement needed for a particular application. The angular displacement between the four cam lobes is illustrated in Figure 4. Cam lobe (24) at the front has its highest point at 300°, cam (25) has its high point at 325°, cam (26) has its high point at 45°, and cam lobe (27) at the rear has its high point at 90°.

Figure 5 illustrates cam (27), for example, rotated about its axis in a clockwise direction while the electron beam (14) is impinging upon its peripheral surface. It has been found that a cam of this shape may be surface hardened to a given depth over its entire wearing surface by the application of an electron beam which is moved rapidly sequentially from spot to spot in accordance with a matrix similar to that shown in matrix (28) of Figure 7 and by causing the beam to be displaced and to dwell in sequence for a presettable period ranging from 30 to 200 microseconds at each of the predetermined spots, and repeating this program of beam motion at rates above 20 frames per second while the cam is rotated at a fixed angular velocity, and the beam current varied in accordance with a predetermined program, related to each angular position of the cam. In the heat treatment of a single cam, the rate of change of electron beam current required lies within the time constant capabilities of the several power supplies utilized in the electron beam generation system. In the simultaneous heat treatment of a multiplicity of cams whose lobes are angularly displaced from one another, it is necessary to generate a matrix at one energy level on the first cam; for example (24), Figure 6, a second matrix on cam (25) at a different energy level, switch to cam (26) for the third matrix generated at a third level, and then to cam (27) for the fourth matrix at a fourth level, and then repeat the process, developing matrices in sequence on (24), (25), (26), and (27) repeatedly while the cam is rotating at a fixed angular velocity.

Changing the power level (rate of energy input) for each matrix by acting on the beam current control is not feasible inasmuch as the high rates of change of beam current required could not be realized because of the relatively long time constant of the high power supply systems required (in the range of 40 to 100 KW). It was found that the necessary rates of change of energy could be obtained by controlling the dwell time of the beam by the relatively low-power, short-time constant deflection circuits of the electron gun while maintaining the overall time to complete each set of four rasters over the four cams being processed. This concept of changing the dwell time of each spot from cam to cam while varying the current at a relatively slow rate so as to deliver the total energy input required by the group of cams at each angular position while proportioning the dwell time at each cam during a given overall period of time in accordance with the total energy requirement of each, resulted in a surface heat treatment on each of the cams which was essentially the same for all. With the development of means for making sufficiently rapid changes in power level of the electron beam, the proportioning of energy delivered to each cam in sequence may be effected solely by varying the power of the electron beam. A multiplicity of cams may be heat treated simultaneously by the process of the present invention, which comprises the steps of:

1. Predetermining the program of energy required in the matrix at each angular position of the cam with respect to the beam,
2. Predetermining the sum of the average powers required at each angular position by all of the cams simultaneously,
3. Rotating the camshaft while varying the energy to conform with the total energy required at

each of the angular positions taken by the cam shaft, and

4. Varying the dwell time of the matrix developed on each of the cams in sequence, so that each cam receives the required average power input at its periphery in accordance with the predetermined program of power with respect to the angular position of a reference axis on each cam with respect to the beam axis.

To summarize, referring to Figure 6, the raster (28) is played upon cam (24) by deflecting the beam from spot to spot. After the completion of one matrix, the beam is deflected to form matrix (29) on cam (25) and upon its completion, matrix (30) is formed on cam (26) and followed by matrix (31) and cam (27). This sequence of beam translation is repeated until the desired heat treatment is effected. As has been predetermined, cams (24) and (25), whose radius and therefore linear velocity are the same at the indicated points of application of the beam, will require the same beam power at these points, whereas cam (26) and cam (27) will each require more beam power because the peripheral velocity of each at the point of application of the beam is greater. In order to distribute the energy in proportion to that which is required at each position of the cam surfaces, the dwell time of the beam upon each of the several cams is varied during the matrix application to produce the required energy application to that portion of the surface of each of the cams. The control (8), acting upon the beam's amplifiers and power supplies, which produce and direct the beam, causes the delivery of the proper energy input at each angular position of each of the cams so as to result in a multiplicity of cams [~~being essentially~~] simultaneously heat treated about each of their peripheries, as illustrated in Figure 8, which in its shaded area (19) shows the uniformity of the heat treatment produced by the process of the present invention.

The foregoing is a description of the method of the present invention, and should not be construed in a limiting sense, but only as describing the underlying concepts involved. The invention should be limited only by the scope of the following claims.

Claims

1. A method of simultaneously surface hardening the work surfaces of a multiplicity of cams by means of a concentrated beam of electrons comprising the steps of:

   rotating a camshaft upon which said cams are formed or held about its longitudinal axis;

   directing and focusing the said beam of electrons to a desired spot on the surface of one of said cams;

   causing the beam to be displaced to and to dwell in sequence for a presettable period ranging from 2-200 micro-seconds at each of a predetermined matrix of spots over a portion of the wear surface of the said cam;

   causing the beam to be displaced and to dwell in sequence as aforesaid on a portion of the wear surface of each of said cams so as to repeat the said matrix on a portion of the surface of each of said cams in turn;

   repeating without interruption the said beam displacement and dwell sequence and matrix over the said multiplicity of cams a preset number of times; and

   controlling the beam current and beam dwell time on each of the separate cams in accordance with a predetermined program, so that the material on the surface of the areas being treated on each of the cams reaches a temperature above the transformation temperature and close to the melting point for said material, substantially simultaneously on all the cams.

2. A method, in accordance with Claim 1, in which the electron beam power density per unit surface of cam is delivered to each cam in sequence in accordance with a predetermined program of power density per unit surface required from spot to spot along the surface of each cam respectively at each of the angular positions taken by each of the cams.

3. A method in accordance with Claim 2 in which the said electron beam power density per unit surface of cam is

varied in accordance with a preset program.

4. A method in accordance with Claim 2 in which the energy per unit surface of cam is varied in accordance with a preset program of variation of beam dwell time with respect to angular position of each cam.

5. A method in accordance with Claim 4 in which the energy per unit surface of cam delivered by the electron beam is varied by varying the electron beam current and the electron beam dwell time in accordance with a preset program of said variations of beam current and beam dwell time with respect to the angular position of each cam.

6. A method in accordance with Claim 4 in which the sum of the dwell times at each of the spots the beam dwells on the group of cams being treated is maintained at a fixed value while the beam current delivered at each point varies in accordance with a preset program of electron beam current with respect to the angular position of the camshaft with respect to a given reference.

7. A cam shaft bearing one or more separate cams whose wear surfaces have been surface hardened by the application of an electron beam to said surfaces while the said camshaft is rotated about its longitudinal axis.

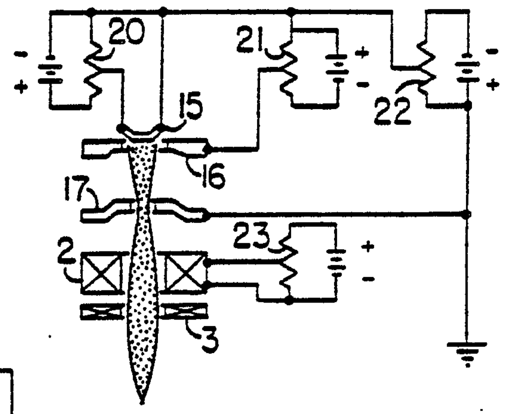
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FIG. 2

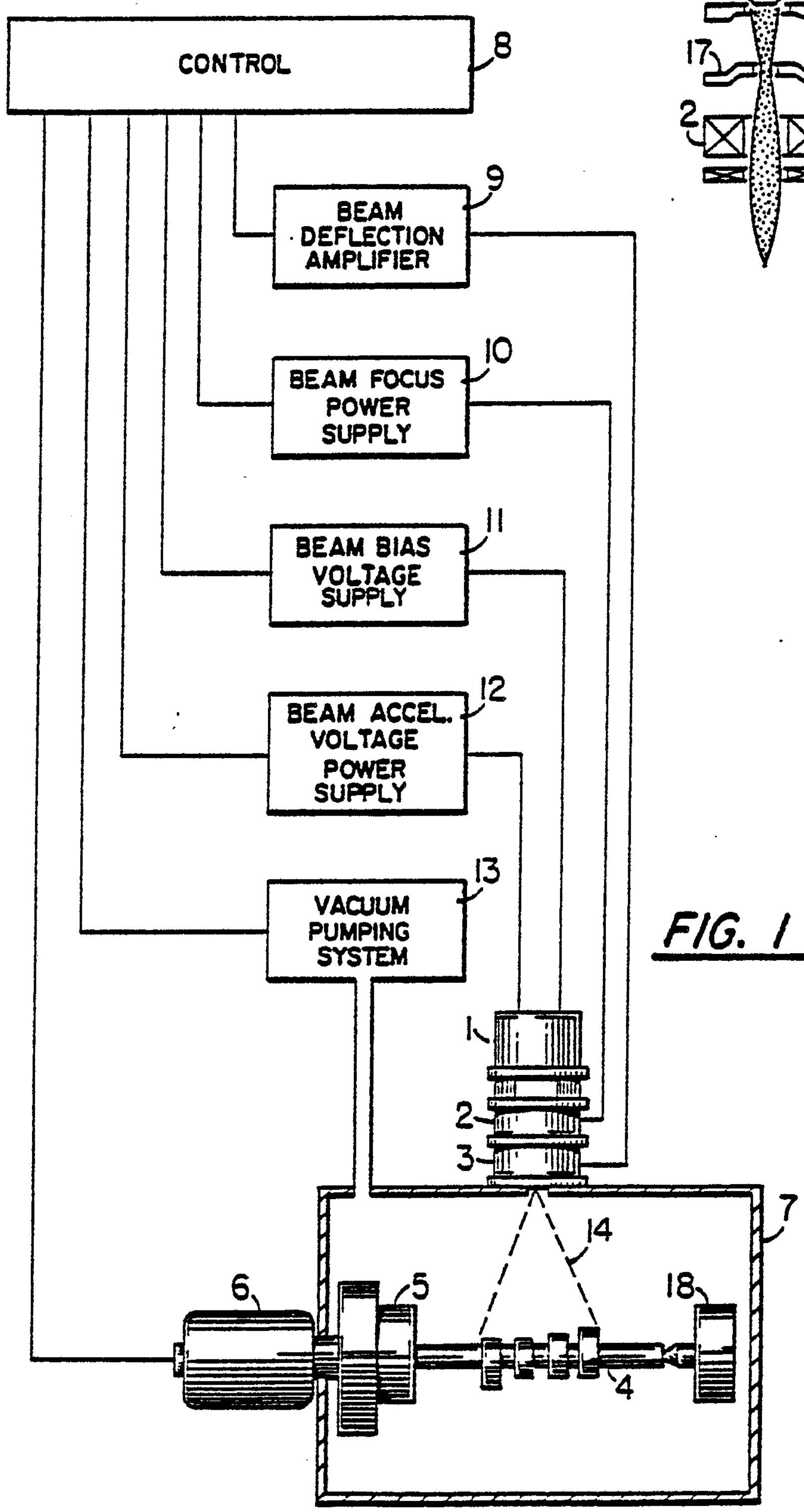
CONTROL
8
BEAM DEFLECTION AMPLIFIER
9
BEAM FOCUS POWER SUPPLY
10
BEAM BIAS VOLTAGE SUPPLY
11
BEAM ACCEL. VOLTAGE POWER SUPPLY
12
VACUUM PUMPING SYSTEM
13
1
2
3
14
7
6
5
18
4

FIG. 1

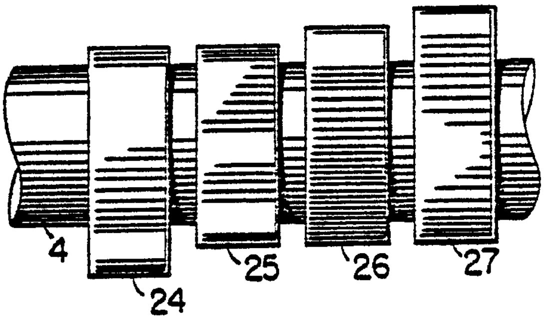

FIG. 3

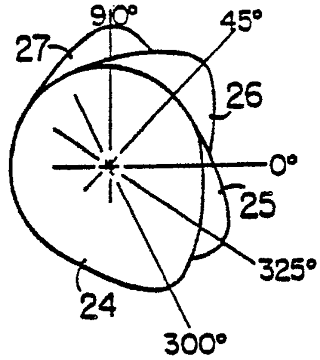

FIG. 4

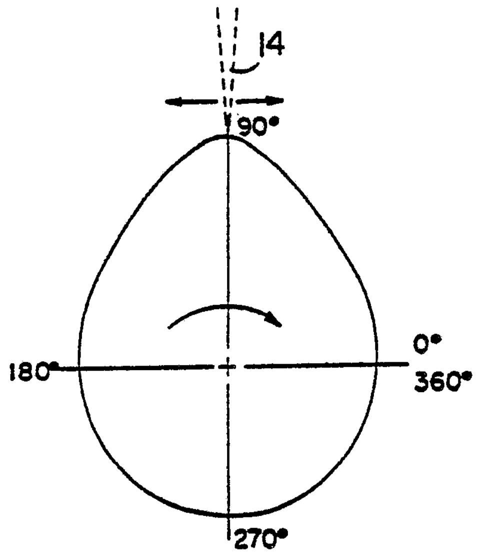

FIG. 5

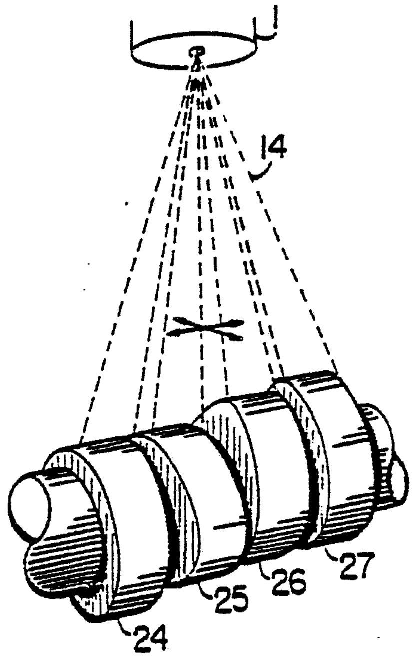

FIG. 6

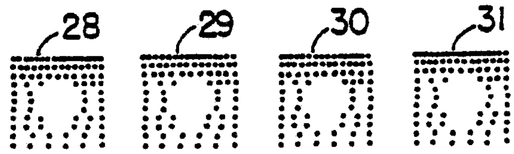

FIG. 7

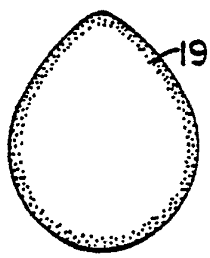

FIG. 8

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 81/00733

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.[3] C23F 7/00; C21D 1/00; C21D 1/06; C21D 1/38; C22C 35/00

US. CL. 148/4; 148/12.7R; 148/13; 148/14; 148/154; 148/39

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
US	148/4; 148/12.4; 148/12.7R; 148/13; 148/14; 148/128; 148/143; 148/145; 148/146; 148/150; 148/154; 148/39

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	US, A, 3,411,380, Published, 19 November 1968, Ehl et al	1-6
X	US, A, 3,650,846, Published, 21 March 1972, Holland et al	1-6
X	US, A, 3,210,518, Published, 05 October 1965, Morley et al	1-6
X	US, A, 3,944,446, Published, 16 March 1976, Bober	7
X	US, A, 3,090,712, Published, 21 May 1963, Berry	7
X	US, A, 2,017,305, Published, 15 October 1935, Campbell	7
A	US, A, 4,043,847, Published, 23 August 1977, Just	1-7
A	US, A, 3,615,905, Published, 26 October 1971, Omsen et al	1-7
A	US, A, 2,800,809, Published, 30 July 1957,	1-7

* Special categories of cited documents: [15]

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"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
16 OCTOBER 1981	22 OCT 1981
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