

ULTRASONIC APPARATUS AND METHOD
FOR CUTTING SHEET MATERIAL

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to application Serial No.
5 168,312, filed July 10, 1980, by Heinz Joseph Gerber and David R.
Pearl, entitled METHOD AND APPARATUS FOR CUTTING SHEET MATERIAL
WITH A CUTTING WHEEL.

BACKGROUND OF THE INVENTION

This invention relates to the field of sheet material
10 cutting, and deals more particularly with an apparatus and method
for cutting a single ply of sheet material, or a thin stack of
such plies, spread over a supporting surface by means of a cutting
tool moved relative to the support surface by a controlled trans-
lating means.

15 Automatically controlled cutting machines for cutting a
single ply of sheet material, or a thin stack of such plies, are
known in the prior art as illustrated in U.S. patents 3,522,752
issued to Schmeid; 3,772,949 issued to Pavone et al; and 3,776,077
issued to Gerber et al. Typical of the types of sheet material
20 cut in the prior art machines are limp sheet material such as
woven and nonwoven fabrics, paper, leather, cardboard, foil and
filamentary sheets or tapes.

The general object of this invention is to provide an
automatically controlled sheet material cutting machine and
25 method providing improved cutting of many materials, including

improved cutting of composite materials such as those consisting of graphite or boron fibers embedded in an uncured or partially cured resin matrix and which are difficult to cut by other means.

Another object of the invention is to provide a cutting machine of the foregoing character wherein the cutting tool cuts with an action which is largely or primarily of a crushing nature, wherein such cutter may cut at a relatively high speed, and wherein forces tending to shift the sheet material in the plane of the support surface are minimized.

Other objects and advantages of the invention will be apparent from the following detailed description of the preferred embodiments.

SUMMARY OF THE INVENTION

The present invention resides in an apparatus and method for cutting sheet material by means of a cutting tool working in combination with a relatively hard supporting surface on which the sheet material is spread. The tool has a cutting surface facing the support surface and further has associated with it an ultrasonic driver which vibrates the cutting surface of the tool at an ultrasonic frequency, and at low amplitude, along an axis generally perpendicular to the support surface. As the cutting surface is so ultrasonically vibrated the tool is moved along a desired line of cut causing the material to be severed by a crushing action as it is ultrasonically squeezed between the tool's cutting surface and the support surface.

The invention also resides in the cutting tool being either in the form of a member defining a cutting surface elongated in one direction parallel to the support surface or in the form of a member having a generally conical end portion defining the cutting surface at its apex or point. The cutting surface itself may define a relatively sharp edge or point, a rounded or spherical surface, or a surface flat in at least one direction.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a cutting apparatus in which the present invention is employed.

Fig. 2 is a side elevational view of the cutter of Fig. 1.

Fig. 3 is a front elevational view of the cutter of Fig. 1.

Fig. 4 is an enlarged side view, partly in elevation and partly in vertical section, showing the mechanism for raising and lowering the cutting tool of the cutter of Fig. 1.

Fig. 5 is a fragmentary side elevational view of the cutting tool of the cutter of Fig. 1.

Fig. 6 is a fragmentary front elevational view of the Fig. 5 cutting tool.

Fig. 7 is a still further enlarged fragmentary front elevational view of the Fig. 5 cutting tool.

Figs. 8 and 9 are views similar to Fig. 7 but show tools with cutting surfaces slightly different from that of Fig. 7.

Fig. 10 is a view similar to Fig. 5 but shows an alternative form of a cutting tool which may be used in the cutter of Fig. 1.

Fig. 11 is a front elevational view of the cutting tool of Fig. 10.

Figs. 12 and 13 are views similar to Fig. 11 but show tools with cutting surfaces slightly different from that of Fig. 10.

Fig. 14 is a view similar to Fig. 5 but shows another alternative form of cutting tool which may be used in the cutter of Fig. 1.

Fig. 15 is a front elevational view of the cutting tool of Fig. 14.

Figs. 16 and 17 are views similar to Fig. 15 but show tools with cutting surfaces slightly different from that of Fig. 15.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 illustrates an automatically controlled cutting machine, generally designated 10, in which the sheet material S to be cut is positioned on a hard, smooth and continuous support surface 14 of a cutting table 16. The machine may be utilized for cutting relatively thin sheet material which is positioned on the support surface 14 in the form of a single ply or in the form of a low stack consisting of only a few plies. The illustrated machine is numerically controlled by means of a controller 18

which guides the cutting tool 11 of a cutter 12 along predetermined lines of cut, such as indicated at P, that define, for example, the periphery of pattern pieces forming a man's dress suit. The contours or shapes of the pattern pieces and the associated lines of cut are defined in a program tape 20 which is read by the controller to produce machine command signals that are transmitted to the cutting table and cutter through a command signal cable 22.

The cutter 12 is suspended above the support surface 14 of the table 16 by means of an X-carriage 26 and a Y-carriage 28. The X-carriage 26 translates back and forth over the support surface in the illustrated X-coordinate direction on a set of racks 30, 32 which are operatively engaged by an X-drive motor 34 energized by command signals transmitted through the cable 22. The Y-carriage 28 is mounted on the X-carriage for movement relative to the carriage 26 in the Y-coordinate direction, and is translated by a Y-drive motor 36 and a lead screw 38 connected between the motor and the carriage 28. Like the drive motor 34, the drive motor 36 is also energized by command signals received through the cable 22 from the controller 18. Thus, coordinated movements of the carriages 26 and 28 translate the cutting tool 11 along any predefined cutting path in the plane of the support surface 14.

In accordance with the invention, the tool 11 of the cutter 12 has a cutting surface, facing the support surface 14,

which engages the sheet material S to be cut and which is vibrated at an ultrasonic frequency toward and away from the support surface, that is along an axis perpendicular to the sheet material such as the illustrated θ axis. This ultrasonic vibration of the tool's cutting surface is maintained as the tool is moved along the desired line of cut with the result that the sheet material is severed by a crushing action resulting from the material of the sheet being ultrasonically squeezed between the tool's cutting surface and the support surface.

The cutting tool and the means for ultrasonically vibrating it may vary, but in the illustrated case, by way of example, the tool is part of an elongated acoustic horn 40 driven by a transducer, consisting of a converter 42 and a booster 44, for converting an alternating electrical signal of ultrasonic frequency into a corresponding ultrasonic frequency mechanical vibration of the horn. The electrical signal is provided by a power supply unit 46 suitably connected with the converter 42 as by means of a cable 48. In Fig. 1 the power supply unit 46 is shown remote from the cutter 12, but if desired it could be mounted on the carriage 28 so as to move with the cutter, or it could also be located in or near the controller 18 with the electrical signal being supplied to the cutter through the cable 22. Power supplies, converters and boosters, such as shown at 46, 42, and 44, are available from Branson Sonic Power Company, Eagle Road, Danbury, Connecticut 06810. Preferably, the tool's

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cutting surface, hereinafter described in more detail, is vibrated at a frequency of between 10,000 Hz and 100,000 Hz, at a relatively low amplitude of vibration, such as a peak-to-peak amplitude of between 0.001 inch and 0.006 inch.

5 The ultrasonic transducer, consisting of the converter 42 and booster 44, is mounted, as shown in Figs. 2 and 3, on an elevator carriage 50 for movement between a lowered position, shown in Figs. 2 and 3, at which the tool 11 is in cutting engagement with the sheet material S, and a raised position at which
10 the tool is out of engagement with the sheet material. The elevator carriage 50 includes a bracket 52 which engages the converter 42 at a vibration node and fixes the converter to the remainder of the carriage and likewise a bracket 54 engages the booster 44 at a vibration node and fixes it to the remainder of
15 the carriage.

For its raising and lowering movement the elevator carriage 50 is slidably supported on two vertical guide rods 56, 56 having their lower ends fixed to a horizontal support plate 58 and their upper ends fixed to a bracket 60 also carried by the
20 support plate. The support plate 58 is apertured to allow the horn 40 to loosely pass through it.

The cutting surface of the tool 11, described in more detail hereinafter, may take various different shapes. In some cases the cutting surface may be elongated in a direction perpendicular to the θ axis, and when this is the case the base plate
25 58 is supported on the carriage 28 for movement about the θ axis,

generally colinear with the longitudinal axis of the tool 11, and a suitable drive mechanism in the carriage 28, controlled by the controller 18, rotates the base plate 58 about the θ axis to maintain the direction of elongation of the cutting surface generally tangent to the line P being cut.

The mechanism for raising and lowering the elevator carriage 50 may vary widely, but preferably it is one whereby in the lowered position of the elevator carriage the cutting tool 11 is urged toward the cutting surface 14 and sheet material S with a predetermined force established by either open loop or closed loop means. The actuator used in such mechanism may be either hydraulically, pneumatically or electrically powered. By way of example, in the illustrated case the raising and lower mechanism consists of a pneumatic actuator 62 fixed to the base plate 58, as shown in Fig. 4, and having a rod 64. At its upper end the rod 64 passes loosely through a drive lug 66 on the carriage 50. A helical compression spring 68 is received in a cylindrical recess in the lug 66 and surrounds the drive rod 64. A slider 70 is also received on the rod 64 and is located between the top end of the spring 68 and an adjusting nut 72 threaded onto the upper end of the rod. Below the lug 66 the rod 64 has fixed to it a collar 74. Pressurized air is supplied to and exhausted from the actuator 62 by pneumatic lines 76, 76.

When the elevator carriage 50 is in its lowered position, as shown in Fig. 4, the piston of the actuator 62 is not

bottomed in its cylinder and the actuator may be supplied with pressurized air at its upper port to apply a downward force to its rod 64. This force is transmitted to the elevator carriage 50 through the compression spring 68 to urge the tool 11 downwardly toward the sheet material S with a force supplementing that of gravity. This additional downward force may be controlled by controlling the pressure of the air supplied to the actuator and this pressure may in turn be ~~may be~~ controlled in either an open loop way, as by a set air supply pressure dictated by the controller 18, or in a closed loop way, as by providing a sensor for detecting the downward force applied to the tool and a means for controlling the air pressure supplied to the actuator 62 so as to maintain such downward force at a preset value. The presence of the compression spring 68 between the actuator 62 and the elevator carriage 50 provides some resiliency for movement of the tool 11 in the vertical direction against the downward force applied by the actuator.

When the elevator carriage and its associated tool 11 are to be raised from the lowered position shown in Fig. 4, the actuator 62 is energized to extend its rod 64, during which extension the fixed collar 74 engages the lug 66 and drives the carriage 50 upwardly to the desired raised position.

As stated, the actual shape of the cutting surface of the cutting tool may take a variety of forms and some forms may be better suited to cutting certain materials than others. Re-

ferring to Figs. 5, 6 and 7 the illustrated cutting tool 11 of Figs. 1, 2 and 3 has an end portion 76 which is cylindrical in its upper region and which below such region is shaped to define a cutting surface in the form of two bevel surfaces 78, 78 which meet to define a relatively sharp, straight and downwardly directed cutting edge 80. At either end of the straight edge 80 the tool is radiused, as at 82, 82, to form a cam-like surface which tends to wedge the sheet material S between the cutting edge 80 and the support surface 14 as the tool is moved in one direction or the other along a line parallel to the cutting edge.

Figs. 8 and 9 show cutting tools with lower end portions 76' and 76'', respectively, which are identical with the lower end portion 76 of Fig. 7 except that the cutting surface does not have a sharp edge such as the edge 80. Instead, in the end portion 76' of Fig. 8 the cutting surface includes two bevel surfaces 78' and 78' which are joined to one another by a flat downwardly facing surface 84. In the tool end portion 76'' of Fig. 9 the cutting surface is defined by two bevel surfaces 78'', 78'' joined by a rounded downwardly facing surface 86.

In the tools of Figs. 7, 8 and 9 the sharp edge 80, the flat surface 84 and the rounded surface 86 are all straight or substantially straight as seen in a side view such as Fig. 5.

Fig. 10 shows another tool 11a having a lower end portion 88. In this tool end portion the upper region is cylindrical and the lower region is formed to provide a convexly

curved cutting surface as seen in side view. As shown in Figs. 10 and 11 such cutting surface is defined by two bevel surfaces 90, 90 which intersect to form a relatively sharp downwardly facing edge 92.

5 Figs. 12 and 13 show alternate forms of the tool 11a of Fig. 10. The tool end portion 88' of Fig. 12 is similar to that of Fig. 11 except that the two bevel surfaces 90', 90' are joined by a downwardly facing surface 94 which is flat when viewed from the front as in Fig. 12. In the tool end portion 10 88'' of Fig. 13 the two bevel surfaces 90'', 90'' are joined by a surface 96 which is rounded when viewed from the front as in Fig. 13.

In all of the tools illustrated in Figs. 5 through 13 the cutting surface is elongated in one direction parallel to the support surface 14 and the tool must be rotated about the θ axis 15 to maintain the elongated direction of the cutting surface tangent to the line of cut. Figs. 14 through 17 show alternate forms of tools wherein the cutting surface is symmetrical about the θ axis so as to require no rotation of the tool. In the tool 20 11b shown in Figs. 14 and 15 the tool includes a lower end portion 98 which is cylindrical in its upper region and which in its lower region has a conical tip 100 defining a sharp cutting point 102. The lower end portion 98' of the Fig. 16 tool is similar to that of Fig. 15 except that the conical tip 100 is truncated and 25 defines a flat circular and downwardly facing surface 104. In

Fig. 17 the tool end portion 98'' has a conical tip 100'' which, instead of being sharply pointed or truncated as in Fig. 15 or 16, has a rounded or generally spherically shaped downwardly facing surface 106.

5 The different shapes of cutting tools illustrated by Figs. 5 through 17 are an exemplary variety from which the particular tool to be used may be selected on the basis of what best suits the characteristics of the material to be cut and other operating factors. Many other shapes may also be used without
10 departing from the invention. In cases where the tool has a surface which is flat in at least one direction, as in the tools of Figs. 8, 12 and 16, the thickness dimension of that flat surface may also vary depending on the nature of the material being cut, and, for example, may range from 0.005 inch and 0.250
15 inch. In cases where the tool includes a surface which is rounded in at least one direction, as in the tools of Figs. 9, 13 and 17 the radius of curvature of such curved surface may vary depending on the material being cut, and for example, may range between 0.005 inch to 0.100 inch.

20 In the aforescribed apparatus, the cutter is urged toward the cutting surface 14 by a downwardly directed force at least a part of which is supplied by the actuator 62. Such an actuator-augmented tool force is not however essential to the broader aspects of this invention and, if desired, the cutting
25 tool in its lowered or cutting position may be urged toward the

supporting surface 14 merely by the weight of the vertically moving parts or by such weight working in conjunction with a spring means which either adds to or subtracts from such weight. As a still further alternative, the displacement of the cutting tool from the support surface may be controlled to maintain, during a cutting operation, a given fundamental positional relationship between the cutting surface of the tool and the support surface 14.

An apparatus wherein the displacement of the cutting tool is controlled is shown in Fig. 18 and includes a cutter 12'. This cutter 12', by way of illustration, is generally similar to the cutter 12 of Fig. 1 except that the elevator carriage 50 has fixed to it a displacement sensor 108, such as one working on the capacitance between it and the supporting surface 14, providing an electrical signal representative of the spacing between the sensor 108 and the surface 14. This signal is transmitted by a cable 110 to a control system and motor 112 which compares the displacement signal from the sensor 108 with a preset value and which adjusts its output rod 114, and the attached elevator carriage 50, vertically to maintain the sensor signal equal to a preset value. This therefore, maintains the sensor at a fixed displacement relative to the supporting surface and accordingly maintains the cutting surface of the associated cutting tool 11 at a fixed fundamental position relative to the supporting surface.

CLAIMS

1. Apparatus for cutting sheet material including material with fibres such as graphite or boron ones difficult to cut with a slicing action using a sharp edged tool, said apparatus comprising: a means
5 defining a hard support surface ~~having a hardness substantially similar to that of steel~~ for supporting at least one layer of sheet material spread thereover, a cutting tool having a cutting
10 surface, translating means for moving said cutting tool and said support surface relative to one another to move said cutting tool along a desired line of cut relative to sheet material spread on said support surface and with said cutting surface of said tool
15 generally facing said support surface and with said sheet material being located and pressed between said support surface and said cutting surface, and means for vibrating said cutting surface of said cutting tool at an ultrasonic frequency toward and away from
20 said support surface while said cutting tool is moved along said line of cut by said translating means so that said sheet material is cut by a crushing action resulting from its being repetitively squeezed at an ultrasonic frequency between said tool cutting
25 surface and said support surface without said cutting surface passing through said support surface.



* C L H S *

2. ~~Apparatus for cutting sheet material as defined in claim 1 further characterized by said support surface being made of steel.~~

3. Apparatus for cutting sheet material as defined in claim 1 further characterized by said means defining a support surface being a table having a planar support surface made of steel and said translating means being a tool carriage movable over said support surface in two coordinate directions and a numerical controller for controlling movement of said carriage in said two coordinate directions.

4.2 Apparatus for cutting sheet material as defined in claim 1 further characterized by said cutting surface being elongated in one plane fixed relative to said tool and perpendicular to said support surface, and said translating means including means for rotating said tool about an axis perpendicular to said support surface to maintain said one plane of said tool at a desired orientation relative to that portion of said line of cut instantaneously encountered by said tool.

5.3 Apparatus for cutting sheet material as defined in claim 1 further characterized by said cutting surface being elongated in one direction generally parallel to said support surface.



44 Apparatus for cutting sheet material as defined in claim ³ further characterized by said cutting surface as seen from a side view having a straight portion generally parallel to said support surface.

5 45 Apparatus for cutting sheet material as defined in claim ³ further characterized by said cutting surface as seen from a side view being of a convex shape.

10 46 Apparatus for cutting sheet material as defined in claim 1 further characterized by said cutting surface being symmetrical about an axis perpendicular to said support surface.

15 47 Apparatus for cutting sheet material as defined in claim ⁶ further characterized by said cutting surface being defined by a tip terminating in a relative sharp point.

48 Apparatus for cutting sheet material as defined in claim ⁶ further characterized by said cutting surface being defined by a tip terminating in a generally circular flat surface.

20 49 Apparatus for cutting sheet material as defined in claim ⁶ further characterized by said cutting surface being defined by a tip terminating in a generally spherical surface.

25 50 Apparatus for cutting sheet material as defined in claim 1 further characterized by means for



urging said cutting surface toward said support surface
while said cutting tool is moved along said line of cut.

5 **N11** Apparatus for cutting sheet material as
defined in claim 10 further characterized by said means for
urging said cutting surface toward said support surface including
an actuator for urging said cutting surface toward said
support surface, and means for applying an energizing medium to
said actuator at a fixed intensity.

10 **N12** Apparatus for cutting sheet material as
defined in claim 10 further characterized by said means for
urging said cutting surface toward said support surface
including an actuator for urging said cutting surface toward said
support surface, a sensor for detecting the force at which
15 said cutting surface is urged toward said support surface,
and means responsive to said detected force for varying
the intensity of an energizing medium applied
to said actuator to maintain said detected force at sub-
stantially a preset value.



5 **¶13** Apparatus for cutting sheet material as defined in claim 1 further characterized by means for maintaining said cutting surface at a fixed fundamental elevation relative to said support surface as said cutting tool is moved along said line of cut.

10 **¶14** Apparatus for cutting sheet material as defined in claim ¹³~~13~~ further characterized by an elevator carriage movable perpendicularly to said support surface and carrying said cutting tool, said means for
15 maintaining said cutting surface of said tool at a fixed fundamental elevation relative to said support surface including a displacement sensor located near said cutting surface and fixed relative to said elevator carriage for sensing the displacement between itself and said support surface, and means responsive to changes in
20 displacement detected by said sensor for moving said elevator carriage perpendicularly of said support surface to return said sensed displacement to a preset value.





N15 Apparatus for cutting sheet material as defined in claim 1 further characterized by said means for vibrating said tool being an ultrasonic electrical to mechanical transducer, and said cutting tool being
5 part of an acoustic horn attached to and driven by said transducer.

N16 Apparatus for cutting sheet material as defined in claim 1 further characterized by an elevator carriage carried by said tool carriage and movable relative to said
10 tool carriage toward and away from said support surface, means for moving said elevator carriage relative to said tool carriage toward and away from said support surface, said means for vibrating said tool
being an ultrasonic electrical to mechanical transducer
15 fixed to said elevator carriage, and said cutting tool being part of an acoustic horn attached to and driven by said transducer.



Q17 A method for cutting sheet material including material with fibres such as graphite or boron ones difficult to cut with a slicing action using a sharp edged tool, said method comprising the steps of: spreading a layer
5 of sheet material over a hard support surface ~~having a hardness substantially similar to that of steel,~~ providing a cutting tool having a cutting surface, moving said cutting tool relative to said support surface along a desired line of cut on the sheet material spread
10 on said support surface with said cutting surface of said tool generally facing said support surface and engaging said sheet material so that said sheet material is located and pressed between said support surface and said cutting surface, and vibrating said cutting surface of said cutting tool
15 at an ultrasonic frequency toward and away from said support surface without substantially penetrating said support surface while said cutting tool is moved along said line of cut whereby said sheet material is cut by a crushing action resulting from its being repetitively squeezed
20 at an ultrasonic frequency between said tool cutting surface and said hard support surface without said cutting surface passing through said support surface.

Q18 ¹⁷ A method for cutting sheet material as defined in claim **Q17** further characterized by urging said tool
25 toward said support surface as it is moved along said line of cut.



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A method for cutting sheet material
as defined in claim ¹⁸20 further characterized by
maintaining the force with which said cutting tool
is urged toward said support surface at a
5 constant value while said cutting tool is moved along
said line of cut.

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A method for cutting sheet material as
defined in claim ¹⁷19 further characterized by maintaining
said cutting surface of said cutting tool at a
10 given fundamental displacement from said support surface
as said cutting tool is moved along said line of cut.

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Apparatus for cutting sheet material
substantially as herein described and shown in the
accompanying drawings.

222

15 A method for cutting sheet material
substantially as herein described with reference to the
accompanying drawings.

