A coil processor is provided for performing processing operations on coiled sheet-like material, such as sheet metal, plastics or other materials. The coil processor uncoils and straightens the material before performing desired operations on the material and transferring it for packaging, shipping or further processing. Various features improve the overall efficiency of the coil processor, including its ability to move material forward and backward through the unit without slowing down the overall operation, as well as the versatility of its mobile tool carriers, which can perform multiple complex processing applications, including cutting, punching, stamping, bending or others. Additionally, processing efficiency may be further enhanced by the use of a computer, which determines the most efficient sequence for performing processing operations, and controls the coil processor's various features to process material in that sequence.
APPARATUS AND METHOD FOR PROCESSING COILED SHEET-LIKE MATERIAL

Field of the Invention

[0001] The present invention relates to coil processors and, more particularly, to apparatus and methods for processing coils of sheet-like material that include conveyors for transporting the sheet-like material, tool carriages with tools for performing work operations on the sheet-like material, and control units for controlling movement of the conveyor, tool carriages and individual tools.

Background Information

[0002] In mechanical engineering, industrial engineering, and other fields, it is often advantageous to process sheet-like material, such as sheet metal or plastic sheet, that is stored in coils. Because the material is originally coiled, and not flat, greater amounts of the material can occupy smaller unit areas in factories or other locations where space is often at a premium, and the material may be transported to the processing site more easily and inexpensively than flat sheet-like materials.

[0003] Methods and apparatus for processing coiled sheet-like material exist in the prior art. Such methods and apparatus generally contemplate unrolling and straightening the coiled material, conveying the straightened material forward through a processor in a first longitudinal direction, and processing the straightened material, before preparing the processed end-product for packaging or further processing. Typical processing applications can include cutting, punching, stamping, bending and/or other operations.

[0004] One of the drawbacks of prior art methods and apparatus for processing coiled sheet-like materials is that the rate of production of the processed end product depends at least in part upon the rate of unrolling of the material from the coil. As a result, any disruption to the unrolling process can reduce the efficiency of processing or production. Additionally, the production rate can be limited by the size of the coil roll, which must be replaced when the material is entirely uncoiled. If the desired processing operation is to occur along varying longitudinal axes in the uncoiled material, the production rate can be further limited by the capacity of the processing unit. If the processing unit cannot move in a second transverse direction with respect to the material, then the coil processor may only perform a single processing operation on the longitudinally moving material passing through the processor. If the
processing unit can move in the second transverse direction, the production rate still can be limited by the complexity of the desired processing operation or the comparative rate of motion of the material in the first direction and the processing head(s) in the second direction. At times, temporarily slowing or halting the unrolling of the sheet-like material may be required to enable the processing head to be placed in the appropriate position, in order to accomplish certain processing operations.

[0005] Additionally, although the art of "coil processing" contemplates several different types of operations, including cutting, punching, stamping, bending and/or other operations, prior art coil processors may be limited to a single processing operation. In many applications, processing units that can perform multiple functions are preferable to those units that can perform only a single function.

[0006] Several existing coil processing units demonstrate both the advantages and the limitations of the prior art. For example, U.S. Pat. No. 3,628,367 to Wilg, entitled "Scroll Cutting and Slitting Machine with Tension Control Means," shows a coil processor including a straightening device, a pair of punching and slitting dies, and a tension means for controlling the basic line speed of the stock material. One of the drawbacks of this type of coil processor is that the punching and slitting dies cannot move transversely relative to the conveyed sheet-like material, and thus cannot perform processing operations on the sheet material in multiple longitudinal axes. Yet another drawback of this type of processor is that it is limited to punching and slitting operations only. Other exemplary prior art coil processors are described in the following patents: U.S. Pat. Nos. 6,742,239 and 6,484,387 to Lee et ah, entitled "Progressive Stamping Die Assembly Having Transversely Movable Die Station and Method of Manufacturing a Stack of Laminae Therewith," and U.S. Pat. No. 6,563,081 to Pace, entitled "Process for the Laser and/or Plasma Cutting of Strips, Particularly Metal Coils, and Relative Continuous Cutting Lines."

[0007] It is an object of the present invention to overcome one or more of the above-described drawbacks and/or other disadvantages of the prior art.

**Summary of the Invention**

[0008] In accordance with a first aspect, the present invention is directed to an apparatus for processing sheet-like material, such as sheet metal or plastic sheet. The apparatus comprises a
number of components connected in series, including a coil, a straightener, a processor and a
conveyor, which moves the material in a first longitudinal direction through each of the
components after uncoiling. Additionally, a slack region exists between two of the units, and
acts as a material accumulation buffer to permit the processing of the material and the uncoiling
of the material to occur independently.

[0009] The processing unit can perform a variety of different processing operations, and
includes at least one tool carrier which can move in a second transverse direction above the
material as it is conveyed through the processing unit. The tool carriers can carry one or more
tools which can independently perform cutting, punching, stamping, bending and/or other
operations on the material as it passes through the processing unit. The present invention can
employ either a single tool carrier or multiple tool carriers to perform processing operations.

[0010] In the present invention, the movement of the material and the tool carrier(s) and the
operation of the individual tools is controlled by a control unit, which can be operated either
manually or automatically. When operated automatically, the control unit uses a computer to
calculate the most efficient sequence of performing the desired processing pattern, in order to
maximize processing efficiency. Desired processing patterns are loaded into the computer and
analyzed; the control unit will determine the most efficient sequence for processing the material
in accordance with the desired pattern. The most efficient sequence is generally that which
minimizes the transverse movement of the tool carrier(s) and utilizes the conveyor's ability to
move the material forward or backward through the processing unit, as necessary.

[0011] In accordance with a second aspect, the present invention is directed to a method for
processing coiled sheet-like material, comprising feeding such material from a rotatably mounted
coil through a processing unit using a tool that moves transversely relative to the movement of
the material, to perform work. The method also comprises forming a slack in the material
downstream of the coil, and moving the material forward or backward through the processing
unit as necessary. The method further comprises using a computer to determine the most
efficient sequence for performing a desired processing pattern; the computer considers the
pattern to be performed, the longitudinal motion of the material to be processed and the
transverse motion of the moving tool in the forward and backward directions in calculating the
optimal processing sequence.

[0012] In some embodiments of the present invention, the method further comprises the
steps of (i) defining a pattern of work operations of the tool(s) on the sheet-like material transported by a conveyor, and (ii) determining for each of a plurality of steps in a first coordinate direction the total movement of the first and second tools in a second coordinate direction for one or more of the following scenarios: (a) movement of first and second tool carriages toward each other, (b) movement of first and second tool carriages in the same direction toward a first side of the sheet-like material, and (c) movement of first and second tool carriages in the same direction toward a second side of the sheet-like material. Some embodiments of the present invention further comprise the step of determining the location of the first and second tools after completing one or more of scenarios (a), (b) and (c) involving the least amount of travel in the second coordinate direction.

Some embodiments of the present invention further comprise the steps of straightening the sheet-like material fed from the coil; and defining a limit of backward movement of the sheet-like material in the first coordinate direction that prevents a need to move sheet-like material in the straightener backwardly in the first coordinate direction. In some such embodiments, the method further comprises the steps of determining the limit of backward movement in the first coordinate direction by determining the processing steps of first and second tools without allowing any backward movement of the conveyor in the first coordinate direction, and then performing multiple iterations of the processing steps of the first and second tools beginning with a minimum of backward movement of the conveyor to a maximum of backward movement of the conveyor with predetermined increments therebetween. Preferably, the method further comprises the steps of determining whether any tools will collide, and if so, moving one or more of the tools relative to the other(s) to avoid collision, performing all of the moves for the other tool(s) in the second coordinate direction, and if necessary to avoid collision, doing the same for the other tools.

In accordance with another aspect, the apparatus further comprises at least one rotatably mounted tool, a motor for rotatably driving the tool, a ring gear drivingly connected to the tool, and a worm gear drivingly connected between the ring gear and the motor. The worm gear includes first and second portions, and at least one of the first and second portions is biased into engagement with the ring gear to substantially prevent backlash of the worm and/or ring gears.

Among the advantages of the present invention is that the sheet-like material can
move both backward and forward in the first longitudinal direction during processing operations. Depending on the desired processing operation, it may be advantageous to change the rate and direction of material travel into the processing unit, in order to perform the desired pattern more efficiently. The capacity to move material both backward and forward can increase processing efficiency over methods and apparatus in the prior art because delays associated with the movement of tool carriers may be minimized. In this regard, the motion of the tool carrier need not limit the rate of processing.

[0016] Another advantage of the present invention is its capacity to accumulate slack in the material during processing operations. The accumulation of slack in a loop situated downstream of the uncoiler enables the material to continue uncoiling even while material is also moving in the backward direction through the processing unit. The accumulation of slack is thereafter reduced when material is advanced through the processing unit in the forward direction at a rate that exceeds the rate of uncoiling.

[0017] A further advantage of the currently preferred embodiments of the present invention is that the tool carrier(s) may perform multiple processing operations independently or simultaneously. The tool carrier(s) of the present invention feature multiple independent processing tools for performing punching, shearing, bending, slitting or other similar operations, along with a rotating tool die head for performing cutting, routing or other similar operations. The mobile tool carriers and the variety of tools housed therein enable the processor to complete complex processing applications and also to perform a wide variety of processing operations without having to replace tools. Additionally, the tool carriers can also reposition the tools in the second transverse direction perpendicular to the material passing through the processing unit.

[0018] Yet another advantage of the currently preferred embodiments of the present invention is that the use of multiple tool carriers enables the processor to complete processing operations more quickly and efficiently than a processor with only one tool carrier.

[0019] Other objects and advantages of the present invention will become readily apparent in view of the following detailed description of currently preferred embodiments and accompanying drawings.

**Brief Description of the Drawings**

[0020] FIG. IA is a side elevational view of a coil processor of the present invention showing the uncoiler, the straightener, the slack region, the conveyor and the processor.
FIG. 1 B is a top plan view of the coil processor of FIG. 1A.

FIG. 2A, FIG. 2B, FIG. 2C and FIG. 2D are top plan, side elevational, front elevational and rear elevational views, respectively, of a C-shaped tool carrier of the coil processor of FIG. 1A and FIG. IB.

FIG. 3A and FIG. 3B are top plan and side elevational views of the tooling carriage and showing tool dies of the coil processor of FIG. 1A and FIG. IB.

FIG. 4A, FIG. 4B and FIG. 4C are a top plan view and elevational views of the front and rear, respectively, of the cylinder manifold of the coil processor of FIG. 1A and FIG. IB.

FIG. 4D and FIG. 4E are side elevational views of the cylinder manifold of the coil processor of FIG. 1A and FIG. IB.

FIG. 5A, FIG. 5B and FIG. 5C are top plan, rear and side elevational views, respectively, of the rotating tool die carriage of the coil processor of FIG. 1A and FIG. IB.

FIG. 6A and FIG. 6B are side elevational and top plan views, respectively, of the rotating tool die of the coil processor of FIG. 1A and FIG. IB.

FIG. 7A and FIG. 7B are a two-part flow chart illustrating the procedural steps performed by the coil processor software in the preferred embodiment, to determine the most efficient processing sequence, in accordance with a method of the present invention.

**Detailed Description of the Currently Preferred Embodiments**

In FIGS. 1-6 a coil processor embodying the present invention is indicated generally by the reference numeral 10. The apparatus 10 comprises a plurality of components in series. A coil 12 containing coiled sheet-like material is positioned within an uncoiler assembly 16, which permits the coiled material to rotate and feed therefrom in a longitudinal or x-coordinate first direction toward a straightener 20, which is positioned to straighten the sheet-like material after it is unrolled from the uncoiler assembly 16. The straightened material leaving the straightener 20 is then fed in the x-coordinate direction to a conveyor unit 30, which translates the material either forward or backward in the x-coordinate direction. Material leaving the conveyor unit 30 enters into the processing unit 32, which includes at least one tool carrier 34, and undergoes the desired processing operation(s) within the processing unit 32. The processed material may then be prepared for storage, shipping or further processing.

The uncoiler assembly 16 comprises a coil 12 with a right cylindric shape and around
which sheet-like material is wrapped. The coil 12 is mounted onto a coil carrier assembly 14 such that the coil 12 can rotate about its axis. The uncoiler assembly 16 uncoils and feeds the sheet-like material in the direction of the straightener 20. In a preferred embodiment, the coil carrier assembly 14 is mounted onto wheels, tracks or other traveling apparatus, such that the coils can be unloaded and replaced when the sheet-like material has been fully uncoiled or otherwise when desired. Additional coil carrier assemblies 14 may be positioned near the apparatus 10 during operation, such that when the sheet-like material has been fully uncoiled or otherwise requires replacement, the coil carrier assembly may be removed and replaced with another or full coil carrier assembly.

[0031] Because the sheet-like material enters the apparatus after having been uncoiled, it will typically have an arcuate shape of varying degree upon exiting the uncoiler assembly 16. The straightener 20 is located downstream of, and receives the sheet-like material fed from the uncoiler assembly 16. In the illustrated embodiment, and by way of a non-limiting example, the material leaving the uncoiler assembly is fed in the direction of the straightener 20 on a ramped roller top table assembly 18. The straightener 20 may comprise a plurality of continuously opposed rollers linked in series, which combine to straighten the sheet-like material as it passes between them, or other apparatus or methods of straightening coiled sheet-like material that are currently known, or that later become known, to those of ordinary skill in the pertinent art. After leaving the straightener 20, the straightened material is then fed in the x-coordinate direction toward the conveyor unit 30. In the illustrated embodiment, and by way of a non-limiting example, the material exits the straightener 20 onto a straightener bridge table assembly 22, which typically comprises a table including a plurality of rollers descending away from the straightener 20.

[0032] A slack region 24 is located between the straightener 20 and conveyor unit 30. The slack region 24 permits the rate of material fed into the processing unit 32 to vary, both forward and backward in the x-coordinate direction, largely independent of the rate of uncoiling from the uncoiler assembly 16. In the illustrated embodiment, and by way of a non-limiting example, the sheet-like material enters the slack region 24 descending onto the straightener bridge table assembly 22, sags into a loop or downwardly directed arcuate shape in the slack region 24, and exits the slack region 24 onto the feeder bridge table assembly 28, ascending in the direction of the conveyor unit 30. If the rate of material fed into the processing unit 32 is less than the rate of
uncoiling from the uncoiler assembly 16, the loop in the slack region 24 will deepen as the sheet-
like material builds up or accumulates therein. If the rate of material fed into the processing unit 32 exceeds the rate of uncoiling from the uncoiler assembly 16, the depth of the loop will be reduced as the material is conveyed out of the slack region 24 and into the processing unit 32. Thus, the slack region 24 acts as a buffer for accumulating material, and enables the processing unit 32 to perform precise operations on the material without affecting the rate of uncoiling from the uncoiler assembly 16. The slack region 24 includes a monitoring unit 26 for monitoring the depth of the loop and transmitting signals indicative thereof to the control unit 38. The monitoring unit 26 may be any of numerous different types of such monitoring units that are currently known, or that later become known, to those of ordinary skill in the pertinent art.

The conveyor unit 30 controls the rate at which the sheet-like material is fed into the processing unit 32. In the illustrated embodiment, and by way of a non-limiting example, the sheet-like material enters the conveyor unit 30 from the feeder bridge table assembly 28. Depending on the processing operation to be performed within the conveyor unit 30, it may be advantageous to change the rate or direction of material travel through the processing unit 32. The conveyor unit 30 can move material either forward or backward in the x-coordinate direction, and is designed to operate independently from the uncoiling of material from the uncoiler assembly 16.

The processing unit 32 is located downstream of the conveyor unit 30, and is comprised of at least one C-shaped tool carrier 34, which can perform various processing operations, including cutting, punching, stamping, bending and/or other operations on the sheet-like material as it is conveyed through the processing unit 32. In the illustrated embodiment, and by way of a non-limiting example, the material leaving the processing unit 32 travels along a conveyor table assembly 36, where the material is packaged or otherwise prepared for distribution or further processing.

As shown in FIGS. 2A, 2B, 2C and 2D, the coil processor 10 includes two C-shaped tool carriers 34 positioned on opposite sides of the conveyor relative to each other, and configured to move in the transverse, or “x”-coordinate, direction relative to the sheet-like material as it passes through the processing unit 32. The tool carriers 34 can move in the “x”-coordinate direction either independently of each other or together in order to perform any of a plurality of different processing operations. In the illustrated embodiment, and by way of a non-limiting
example, tool carriers 34 are positioned on linear bearings 68 with individual servo drive motors (not shown). However, other methods of positioning the tool carriers 34 that are known, or may become known, may be used to perform the positioning function.

[0036] Although the preferred embodiment includes two tool carriers 34, any number of tool carriers of any of numerous different configurations that are currently known, or that later become known, may be employed. For example, a single tool carrier may be employed if desired, or alternatively, multiple pairs of tool carriers may be employed in series if the desired operations require such a configuration.

[0037] The tool carriers 34 can perform a number of different functions in order to accomplish the desired processing of the sheet-like material. As shown in FIGS. 2A, 2B and 2C, the tool carriers 34 are connected to electrical, hydraulic and other services for use during coil processing, and can accommodate different processing apparatus, such as the tooling carriage 42 and the rotating die tool carriage 40. Because the tool carrier 34 can operate with interchangeable apparatus, it can perform a variety of different processing operations on sheet-like materials of different shapes, sizes, thicknesses and types. Each tool carrier 34 can process sheet-like material using either the tooling carriage 42 or the rotating tool die carriage 40 independently, or by using both components simultaneously.

[0038] Punching, shearing and similar processing operations may typically be performed with the tooling carriage 42, which includes a plurality of tool dies 46 and is mounted to the base plate of the cylinder manifold 44. The cylinder manifold 44 includes internal hydraulic piping, valves and other components that enable the independent operation of the tool dies 46. In the illustrated embodiment of the present invention, and by way of a non-limiting example, the cylinder manifold 44 and tooling carriage 42 can accommodate up to ten different tool dies 46, which can be actuated independently. Because the tooling carriage 42 can accommodate multiple tools, the coil processor 10 can accomplish a number of different processing tasks without adjusting or replacing the carriage(s). However, in order to minimize processing downtime, separate tooling carriages 42 may be readied independent of the processor operation so that they may be installed into the tool carrier 34 if necessary.

[0039] The tooling carriage 42 is installed into the tool carrier 34 by mating the tool dies 46 in the carriage with the respective cylinders 64 of the cylinder manifold 44 mounted in the upper interior surface of the tool carrier 34. If desired, each tool die 46 can be connected to electrical
power, hydraulic power and/or other power sources or services independently of the tool carrier 34. The cylinder manifold 44 contains internal hydraulic lines and valves which provide sufficient hydraulic pressure to permit each cylinder 64 to be actuated independently, and to perform the desired processing operation. Once actuated, each cylinder 64 presses the respective tool die 46 downward in a third or z-coordinate direction substantially perpendicular to the plane of the material travel through the processing unit 32. In this manner, each tool die 46 can independently perform punching, shearing and/or other operations on the sheet-like material.

[0040] As shown in FIGS. 3A and 3B, the illustrated embodiment of the tooling carriage 42 includes ten tool dies 46 of varying sizes, shapes and functions. As shown in FIG. 4D and FIG. 4E, each cylinder 64 in the cylinder manifold 44 includes hydraulic supply lines 48 and hydraulic return lines 50 which enable each of the cylinders 64 to be extended or retracted independently of each other. As may be recognized by those of ordinary skill in the pertinent art based on the teachings herein, the cylinder manifold 44 and tooling carriage 42 may include any number of cylinders 64 and tool dies 46 that are desired or otherwise required, and may include any of a variety of different types of tools for processing the sheet-like material that are currently known, or that later become known, to those of ordinary skill in the pertinent art.

[0041] Turning to FIGS. 5A, 5B and 5C, the rotating tool die carriage 40 is generally used to perform cutting, grinding, routing and/or other desired operations on the sheet-like material. The rotating tool die carriage 40 is installed into the respective tool carrier 34 by connecting it with a single hydraulic cylinder 70 or other apparatus, which drives the rotating tool die in the z-coordinate direction. Typically, the rotating tool die carriage 40 features a single tool, such as a blade or other cutting device, which is placed into the appropriate position in the z-coordinate direction by the cylinder 70. In order to maintain precise control over the tool depth during processing operations, the cylinder 70 in the rotating tool die carriage 40 contains servo-actuated hydraulic valves (not shown) which position the tool in the z-coordinate direction to a desired degree of accuracy. This function may be performed by other apparatus that are currently known, or that later become known, to those of ordinary skill in the pertinent art. As may be recognized by those of ordinary skill in the pertinent art based on the teachings herein, the rotating tool die carriage 40 may include any of a variety of different tools and/or different tool types that are currently known, or that later become known, for performing any of a variety of different work operations on sheet-like material.
As shown in FIG. 5A, 5B, 5C and 6A, the rotating tool die carriage 40 includes an upper rotating head 54 and a lower rotating head 56, which are substantially synchronously rotated by a servo motor 52 or other type of drive unit that is currently known, or that later becomes known, to those of ordinary skill in the pertinent art for performing this function. As shown in FIGS. 5B and 5C, in the illustrated embodiment, the servo motor 52 is drivingly connected to the upper rotating head 54 and a lower rotating head 56 by a pair of shafts 60. A pulley system comprising at least one pulley 58 is used to transfer rotational energy from the servo motor 52 to the individual shafts 60.

As shown in FIG. 6B, one end of each of the shafts 60 is respectively coupled to the upper rotating head 54 and a lower rotating head 56 by worm gears 62A, 62B which are positioned near the ends of the shafts 60, and positively bias against the ring gear 66. A tool, such as a blade or other processing device, is mounted to the upper rotating head 54, and is pressed into the appropriate processing position in the sheet-like material in the z-coordinate direction by the cylinder 70. The lower rotating head 56 defines a slot having a shape substantially identical to that of the respective tool, but a size slightly larger than that of the tool so that the tool may enter the slot if it partially or fully penetrates the sheet-like material during processing.

The rotational position of the slot in the lower rotating head 56 must approximately match the rotational position of the tool installed into the upper rotating head 54, to enable the tool to insert into the slot upon partial or full penetration of the sheet-like material. Therefore, the rotation of the heads is preferably synchronized, using a servo motor 52 and pulley system as described above, or other apparatus known, or that may become known, to those skilled in the pertinent art. To accomplish this function, the worm gear 62A, 62B on the respective shafts 60 maintains a substantially constant bias on the ring gear 66 on the respective rotating heads 54, 56 to minimize backlash. In the illustrated embodiment, and as shown in FIG. 6B, the worm gear 62A, 62B is split approximately in half; the inner half of the worm gear 62A is appropriately positioned on the ring gear 66 during assembly of the gearset, after which the outer half of the worm gear 62B is installed along with a gear spring (not shown), which maintains the halves of the worm gear 62A, 62B substantially in contact with the ring gear 66. However, other methods and apparatus for minimizing the backlash on the worm gear 62A, 62B and ring gear 66 may be utilized, including those that are currently known, or that later become known, to those of
ordinary skill in the pertinent art.

[0045] One advantage of the coil processor 10 is that its components, including tool carriers 34, independent tool dies 46, conveyor unit 30, and others if desired, can operate either manually at the direction of a human operator, or automatically as directed by the control unit 38, to perform any of a variety of desired processing operations. The control unit 38 includes software that determines the most efficient sequence to accomplish the desired processing operations by controlling the material feed rate in the x-coordinate direction, the lateral movement of the tool carriers 34 in the y-coordinate direction, and the operation of the individual tool dies 46 of the tool carriage and/or the single tool die 46 in the rotating tool carriage in the z-coordinate direction when performing processing operations.

[0046] Turning to FIG. 7, the software resident on the control unit 38 determines the most efficient processing sequence for performing the desired processing pattern. In the illustrated embodiment, at the outset of operations, as is shown in step S.1, pattern data is programmed into the control unit 38, such as by manual entry via a keyboard, mouse or other data input apparatus; transfer from floppy discs, CD-ROMs, DVD-ROMs, external hard drives, RAM drives or other data storage devices; by download from external data sources such as the Internet or an internal computer network ("Intranet"); or by any of numerous other apparatus or methods that are currently known, or that later become known. In the preferred embodiment, two tool carriers 34 are directly opposed to one another on either side of the sheet-like material passing through the processor unit 32, and a central processing unit (CPU) 72 of the control unit 38 utilizes the onboard software and the data entered to optimize the desired processing pattern in a sequence as hereinafter described.

[0047] In step S.2, optimizing software breaks down the desired processing pattern into movements of each tool carrier 34 in the ^x-coordinate direction for every position of the material in the x-coordinate direction. Each collection of individual tool carrier 34 movements in the y-coordinate direction at a single material position in the x-coordinate direction is analyzed, for each step of the pattern. Next, in step S.4, the CPU calculates the total movement required by the tool carriers 34 in the y-coordinate direction to complete the desired operations at the initial material position in the x-coordinate direction at the beginning of the desired pattern, for at least the following carrier movement scenarios: (i) movement of the tool carriers 34 inward toward each other; (ii) movement of the tool carriers 34 in the same direction toward one side of the
sheet-like material; and (iii) movement of the tool carriers 34 in the same direction toward a second side of the sheet-like material. In step S.5, the CPU 72 chooses the scenario in which the aggregate movement of the tool carriers 34 is minimized while accomplishing the desired processing operation for the first material unit step of the processing pattern in the x-coordinate direction.

After a carrier movement scenario is originally selected, the CPU 72 then determines in step S.6 where the tool carriers 34 must be positioned in the ^-coordinate direction in order to perform the desired processing operation at the next material location in the x-coordinate direction. If the scenario originally selected by the CPU 72 would leave the tool carriers 34 in a position that would require excessive movement (or movement greater than a predetermined distance or other amount) to perform the desired processing operation at the next material location in the x-coordinate direction, the CPU 72 will return to step S.5 and revisit its selection, to consider whether either of the remaining two scenarios identified, for example, as (i), (ii) and/or (iii) above would place the tool carriers 34 in a more optimal position to accomplish the next processing operation. If either scenario would provide less movement of the tool carriers 34 to perform the desired processing operation at the next material unit step in the x-coordinate direction, the CPU 72 will abandon its original selection and choose one of the two remaining scenarios which was not originally selected. If neither of the two remaining scenarios would improve the position of the tool carriers 34 to accomplish the processing operation at the next material unit step in the x-coordinate direction, the CPU 72 will adhere to the scenario that was originally selected, in whole or in part.

The process described above in steps S.4 through S.7 is repeated to determine the best carrier movement scenarios to perform all of the processing operations of the desired pattern, at each of the pattern's material positions in the x-coordinate direction.

Once the best carrier movement scenarios for all of the processing operations in the pattern have been selected, the CPU 72 then separates the respective movements of the individual tool carriers 34 in the ^-coordinate direction into pairs of material unit steps in the x-coordinate direction. The CPU 72 "looks ahead" to a fixed number of future material unit steps in the x-coordinate direction to determine whether the future processing operations could be completed more efficiently by performing a portion of the desired pattern on the forward-moving material with limited or no carrier movement in the ^-coordinate direction, then "backing up" the
material in the x-coordinate direction while repositioning the tool carriers in the ^-coordinate direction, and moving the material forward again in the x-coordinate direction to perform another portion of the pattern on the forward-moving material, until the desired processing pattern has been fully completed. As described above, the conveyor unit 30 may move the material backward in the x-coordinate direction through the processing unit 32 while material continues to uncoil from the uncoiler assembly 16, and any excess material accumulates in the loop located in the slack region 24. This feature can improve processing efficiency by minimizing overall carrier movement, and by repositioning carriers while the material is "backing up" through the processing unit 32.

[0051] In steps S.10 through S.16, the CPU 72 determines the amount of material "back up," if any, that would minimize the tool carrier 34 travel in the ^-coordinate direction required to perform the programmed processing pattern by calculating the combined tool carrier 34 travel in the ^-coordinate direction for a series of material unit step iterations in the x-coordinate direction, up to a pre-set maximum allowable number of "back up" material unit steps. The maximum number of "back up" material unit steps is generally defined by the length and depth of the slack region 24, which determines how much material may be backed up into the loop during operations. To set a baseline datum, the CPU 72 first calculates the amount of carrier travel in the ^-coordinate direction required to perform the processing operations in the desired pattern without using any "back up," and stores this value in memory. The CPU 72 then calculates the total amount of carrier travel in the ^-coordinate direction for a series of iterations of "back up" material unit steps in the x-coordinate direction, up to the maximum allowable number of such steps, and stores these in memory. After the iteration for the maximum allowable number of material unit steps has been calculated and stored in memory, the CPU 72 selects a sequence using the amount of "back up" corresponding to the iteration with the least total carrier travel in the y-coordinate direction. If each of the iterations causes either an increase or no change in the total amount of carrier travel, the baseline datum with no "back up" in the x-coordinate direction is selected to process the sheet material.

[0052] Finally, in step S.18, the CPU 72 considers whether the most efficient sequence determined by the iterative process outlined above would cause the tool carriers 34 to collide while completing the processing operation. If a collision would occur, the CPU 72 alters the processing sequence in step S.19 by directing the tool carriers 34 to clear one another, and may
pause or reverse the material in the x-coordinate direction as necessary to permit the processing sequence to be completed. Once the best carrier movement scenario and processing sequence have been selected, the material is processed.

[0053] As may be recognized by those or ordinary skill in the pertinent art based on the teachings herein, numerous changes and modifications may be made to the above-described and other embodiments of the present invention without departing from its scope as defined in the appended claims. For example, the coil processor may process any of numerous different types of sheet-like material that are currently known, or that later become known, such as different types of metal, plastic, laminates, or other types of materials. The coil processor may utilize different tools for cutting, punching, stamping, bending and/or other operations. Further, the coil processor may be operated using either the tool carriage, the rotating tool carriage, or both. Additionally, more components can be added to those described herein, and some of the described components may be combined into single components, for example, a combination conveyor unit and straightener unit may be used. Moreover, the onboard software in the control unit may be updated or replaced with improved software by methods that are currently known, or that later become known, to those of ordinary skill in the pertinent art, in order to improve the efficiency of operation or for any other reason. Accordingly, this detailed description of currently preferred embodiments is to be taken in an illustrative as opposed to limiting sense.
What is claimed is:

1. An apparatus for processing coiled sheet-like material, comprising:
   a rotatably mounted coil of sheet-like material that is rotated to feed the sheet-like material therefrom;
   a conveyor located downstream of the coil for receiving the sheet-like material fed from the coil and transporting the sheet-like material forwardly and backwardly in a first coordinate direction;
   at least one tool mounted adjacent to the conveyor and movable relative to the sheet-like material supported thereon in a least one second coordinate direction for performing work on the sheet-like material; and
   a slack portion of the sheet-like material located downstream of the coil for permitting backward movement of the sheet-like material on the conveyor in the first coordinate direction.

2. An apparatus as defined in claim 1, wherein the at least one tool is located downstream of the slack portion of the sheet-like material.

3. An apparatus as defined in claim 2, further comprising a straightener located between the coil and the slack portion of the sheet-like material for performing at least one straightening operation on the sheet-like material.

4. An apparatus as defined in claim 1, wherein said sheet-like material forms a loop of varying dimensions in said slack portion during the conveyance of material.

5. An apparatus as defined in claim 1, further comprising a control unit operatively coupled to the conveyor and the at least one tool for controlling movement of the conveyor in the first coordinate direction, and controlling movement of the at least one tool in the second coordinate direction.

6. An apparatus as defined in claim 5, further comprising a first tool carriage including at least one first tool mounted thereon, and a second tool carriage including at least one second tool mounted thereon, wherein each of the first and second tool carriages is movable relative to the sheet-like material transported by the conveyor in a least one second coordinate direction for performing work on the sheet-like material.

7. An apparatus as defined in claim 6, wherein each of the first and second tool carriages is movable transversely relative to the sheet-like material transported by the conveyor in the second coordinate direction, and at least a plurality of the first and second tools are
movable vertically relative to the sheet-like material transported by the conveyor in a third coordinate direction.

8. An apparatus as defined in claim 7, wherein the first and second tool carriages are mounted on substantially opposite sides of the conveyor relative to each other.

9. An apparatus as defined in claim 7, wherein the first, second and third coordinate directions are mutually orthogonal.

10. An apparatus as defined in claim 5, wherein the control unit moves the conveyor and sheet-like material transported thereon backwardly in the first coordinate direction to substantially minimize movement of the at least one tool in the second coordinate direction.

11. An apparatus as defined in claim 8, wherein the control unit receives data defining a pattern of work operations of the at least one tool on the sheet-like material transported by the conveyor, the data defines a plurality of steps of the sheet-like material and conveyor in the first coordinate direction, and the control unit determines for each of a plurality of steps in the first coordinate direction the total movement of the first and second tools in the second coordinate direction for at least one of the following scenarios: (i) movement of the first and second tool carriages toward each other, (ii) movement of the first and second tool carriages in the same direction toward a first side of the sheet-like material, and (iii) movement of the first and second tool carriages in the same direction toward a second side of the sheet-like material.

12. An apparatus as defined in claim 11, wherein the control unit determines the least amount of travel of the first and second tools in the second coordinate direction under each of a plurality of scenarios (i), (ii) and (iii).

13. An apparatus as defined in claim 12, wherein the control unit determines the location of the first and second tools after completing one of scenarios (i), (ii) and (iii) involving the least amount of travel in the second coordinate direction.

14. An apparatus as defined in claim 13, wherein the control unit divides the movements of the first and second tools in the second coordinate direction into pairs of steps in the first coordinate direction, and determines which pairs of steps in the first coordinate direction would reduce overall travel of the first and second tools in the first and second coordinate directions.

15. An apparatus as defined in claim 1, further comprising a straightener located between the coil and the slack portion of the sheet-like material for performing at least one
straightening operation on the sheet-like material; and a control unit operatively coupled to the
conveyor and the at least one tool for controlling movement of the conveyor in the first
coordinate direction, and controlling movement of the at least one tool in the second coordinate
direction, wherein the controller defines a limit of backward movement of the sheet-like material
in the first coordinate direction that prevents a need to move any sheet-like material in the
straightener backwardly in the first coordinate direction.

16. An apparatus as defined in claim 15, wherein the control unit determines the limit
of backward movement in the first coordinate direction by determining the processing steps of
the first and second tools without allowing any backward movement of the conveyor in the first
coordinate direction, and then processes multiple iterations of the processing steps of the first
and second tools beginning with a minimum of backward movement of the conveyor to a
maximum of backward movement of the conveyor with predetermined increments therebetween.

17. An apparatus as defined in claim 14, wherein the control unit determines whether
at least one of the first and second tools will collide, and if so, the control unit moves one of the
first and second tools relative to the other to avoid collision, performs all of the moves for the
other of the first and second tools in the second coordinate direction, and if necessary to avoid
collision, does the same for the other of the first and second tools.

18. An apparatus as defined in claim 6, wherein each tool carriage includes a plurality
of tools and a plurality of cylinders, and each cylinder is drivingly coupled to a respect tool to
drive the respective tool in the third coordinate direction independently of the other tools.

19. An apparatus as defined in claim 18, wherein the cylinders are hydraulic
cylinders.

20. An apparatus as defined in claim 19, wherein the tools are punches.

21. An apparatus as defined in claim 1, wherein at least one tool is rotatably mounted,
and includes a motor for rotatably driving the tool, a ring gear drivingly connected to the tool,
and a worm gear drivingly connected between the ring gear and the motor, wherein the worm
gear includes first and second portions, and at least one of the first and second portions is biased
into engagement with the ring gear to substantially prevent backlash of at least one of the worm
and ring gears.

22. An apparatus as defined in claim 1, wherein the sheet-like material is sheet metal.

23. An apparatus for processing coiled sheet-like material, comprising:
first means for rotatably mounting a coil of sheet-like material and feeding the sheet-like material therefrom;

second means located downstream of the first means for receiving the sheet-like material fed from the first means and transporting the sheet-like material forwardly and backwardly in a first coordinate direction;

third means mounted adjacent to the second means and movable relative to the sheet-like material supported thereon in a least one second coordinate direction for performing work on the sheet-like material; and

fourth means located downstream of the first means for permitting backward movement of the sheet-like material on the second means in the first coordinate direction.

24. An apparatus as defined in claim 23, wherein the first means is a rotatably mounted coil of sheet-like material, the second means is a conveyor, the third means is at least one tool, and the fourth means is a slack portion of the sheet-like material.

25. An apparatus as defined in claim 23, further comprising fifth means for performing at least one straightening operation on the sheet-like material fed from the first means.

26. An apparatus as defined in claim 23, further comprising sixth means for controlling movement of the second means in the first coordinate direction, and controlling movement of the third means in the second coordinate direction.

27. An apparatus as defined in claim 23, further comprising seventh means for moving the second means and sheet-like material transported thereon backwardly in the first coordinate direction and substantially minimizing movement of the third means in the second coordinate direction.

28. A method for processing coiled sheet-like material, comprising the following steps:

rotatably mounting a coil of sheet-like material and feeding the sheet-like material therefrom;

receiving the sheet-like material fed from the coil onto a conveyor and transporting the sheet-like material on the conveyor in a first coordinate direction;
moving at least one tool relative to the sheet-like material supported on the conveyor in a least one second coordinate direction and performing work with the tool on the sheet-like material; and

forming a slack in the sheet-like material downstream of the coil, moving the sheet-like material on the conveyor backwardly in the first coordinate direction, and taking up the sheet-like material moved backwardly in the first coordinate direction with the slack.

29. A method as defined in claim 27, further comprising performing at least one straightening operation on the sheet-like material fed from the coil.

30. A method as defined in claim 27, further comprising providing a first tool carriage including at least one first tool mounted thereon, and a second tool carriage including at least one second tool mounted thereon, and moving each of the first and second tool carriages relative to the sheet-like material transported by the conveyor in a least one second coordinate direction and performing work with the first and second tools on the sheet-like material.

31. A method as defined in claim 30, further comprising the steps of moving the first and second tool carriages transversely relative to the sheet-like material transported by the conveyor in the second coordinate direction, and moving at least a plurality of the first and second tools vertically relative to the sheet-like material transported by the conveyor in a third coordinate direction.

32. A method as defined in claim 31, further comprising mounting the first and second tool carriages on substantially opposite sides of the conveyor relative to each other.

33. A method as defined in claim 31, wherein the first, second and third coordinate directions are mutually orthogonal.

34. A method as defined in claim 31, further comprising the step of moving the conveyor and sheet-like material transported thereon backwardly in the first coordinate direction and substantially minimizing movement of the at least one tool in the second coordinate direction.

35. A method as defined in claim 31, further comprising the steps of defining a pattern of work operations of the at least one tool on the sheet-like material transported by the conveyor, including a plurality of steps of the sheet-like material and conveyor in the first coordinate direction, and determining for each of a plurality of steps in the first coordinate direction the total movement of the first and second tools in the second coordinate direction for
at least one of the following scenarios: (i) movement of the first and second tool carriages toward each other, (ii) movement of the first and second tool carriages in the same direction toward a first side of the sheet-like material, and (iii) movement of the first and second tool carriages in the same direction toward a second side of the sheet-like material.

36. A method as defined in claim 35, further comprising the step of determining the least amount of travel of the first and second tools in the second coordinate direction under each of a plurality of scenarios (i), (ii) and (iii).

37. A method as defined in claim 36, further comprising the step of determining the location of the first and second tools after completing one of scenarios (i), (ii) and (iii) involving the least amount of travel in the second coordinate direction.

38. A method as defined in claim 37, further comprising the step of dividing the movements of the first and second tools in the second coordinate direction into pairs of steps in the first coordinate direction, and determining which pairs of steps in the first coordinate direction would reduce overall travel of the first and second tools in the first and second coordinate directions.

39. A method as defined in claim 31, further comprising the steps of straightening the sheet-like material fed from the coil; and defining a limit of backward movement of the sheet-like material in the first coordinate direction that prevents a need to move any sheet-like material in the straightener backwardly in the first coordinate direction.

40. A method as defined in claim 39, further comprising the steps of determining the limit of backward movement in the first coordinate direction by determining the processing steps of the first and second tools without allowing any backward movement of the conveyor in the first coordinate direction, and then performing multiple iterations of the processing steps of the first and second tools beginning with a minimum of backward movement of the conveyor to a maximum of backward movement of the conveyor with predetermined increments therebetween.

41. A method as defined in claim 40, further comprising the steps of determining whether at least one of the first and second tools will collide, and if so, moving at least one of the first and second tools relative to the other to avoid collision, performing all of the moves for the other of the first and second tools in the second coordinate direction, and if necessary to avoid collision, doing the same for the other of the first and second tools.
42. A method as defined in claim 31, further comprising the steps of providing a plurality of punches, and independently actuating each of a plurality of the punches relative to the others.

43. A method as defined in claim 31, further comprising the steps of providing at least one rotatably mounted tool, a motor for rotatably driving the tool, a ring gear drivingly connected to the tool, and a worm gear drivingly connected between the ring gear and the motor, wherein the worm gear includes first and second portions, and biasing at least one of the first and second portions of the worm gear into engagement with the ring gear to substantially prevent backlash of at least one of the worm and ring gears.
DATA ENTRY FOR DESIRED PROCESSING PATTERN

SEPARATE PATTERN INTO CARRIER Y-MOVEMENTS FOR MATERIAL X-POSITIONS

BEGIN PATTERN ANALYSIS AT INITIAL MATERIAL X-POSITION

CALCULATE TOTAL CARRIER Y-MOVEMENTS TO PERFORM PROCESSING OPERATION AT MATERIAL X-POSITION FOR SCENARIOS (I), (II), (III)

FROM AVAILABLE SCENARIOS, SELECT SCENARIO WHICH PERFORMS PROCESSING OPERATION WITH LEAST TOTAL CARRIER Y-Movement

DETERMINE CARRIER POSITION IN Y-DIRECTION REQUIRED TO PERFORM OPERATION AT NEXT MATERIAL X-POSITION

DOES SELECTED SCENARIO LEAVE CARRIER IN BEST Y-POSITION TO PERFORM PROCESSING OPERATION AT NEXT MATERIAL X-POSITION IN PATTERN?

ADVANCE MATERIAL TO NEXT X-POSITION FOR ANALYSIS

SCENARIO ANALYSIS COMPLETE FOR ALL X-MOVEMENTS IN PATTERN?

YES

SEPARATE INDIVIDUAL CARRIER Y-MOVEMENTS INTO PAIRS CORRESPONDING TO MATERIAL X-MOVEMENTS

BEGIN "BACK UP" ANALYSIS AT INITIAL MATERIAL X-POSITION

NO

FIG. 7A
BEGIN "BACK UP" ANALYSIS AT INITIAL MATERIAL X-POSITION

SET NO. OF "BACK UP" STEPS = S = 0

CALCULATE TOTAL COMBINED CARRIER Y-MOVEMENT USING S "BACK UP" STEPS IN X-DIRECTION

STORE TOTAL CARRIER Y-MOVEMENT USING S "BACK UP" STEPS IN X-DIRECTION

S = S + 1

S15

S16

S17

SELECT PROCESSING SEQUENCE WITH LEAST CARRIER MOVEMENT USING S "BACK UP" STEPS IN X-DIRECTION

S18

WILL CARRIERS COLLIDE IF SCENARIOS AND SEQUENCES SELECTED ABOVE ARE USED IN PROCESSING?

S19

NO

MODIFY PROCESSING SEQUENCE TO AVOID COLLISION DURING PROCESSING

YES

PROCESS MATERIAL USING SCENARIOS AND SEQUENCES SELECTED ABOVE

FIG. 7B