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(54) A method for spreading and cutting flexible sheet materials

(57) SUMMARY OF THE INVENTION

Accordingly with the invention, during the spreading phase, plies stacked in each cutting position can be separated into different groups by applying one flexible film ply, called "separator film" between groups. The application of the separator film is provided by means of a "separating spreader". It is desirable to provide an apparatus for separating plies that is efficient and does not increase sheet material spreading time. It is an object of the present invention in its preferred embodiment at least to provide a method for applying separating film that minimize the time required for spread separating film. It is a further object of the present invention in its preferred embodiment at least to provide a method for accommodates a separating film at different heights at different cutting positions in the lay-up. It is a another object of the present invention in its preferred embodiment at least to provide a method that ensure that the separating film is applied without both stopping the sheet material spreading and requiring a spreader set-up operation. Moreover in accordance with the present invention, the spreader is provided by an innovative operating method oriented to the minimization of the number of lay-ups formed Indeed, the lower are the spreading time and the cutting time spent to process the current workload, the higher are the productivity performance of the system. Since the cutting patterns are pre-established, it is an object of the present invention to provide a method to compose single lay-up in order to maximize the length of spread plies (i.e. to minimize supply roll changes and the number of distinct spreading operations) as well as to maximize cutting positions heights (i.e. minimize of the number of cutting positions). The provided method is subject to constraints inherent the spreader worktable length and the maximum number of plies that can be cut at once. It is a further object of the present invention to provide a method to manage the spreading operation taking into account the mirror properties of cutting patterns, placed in contiguous cutting positions.

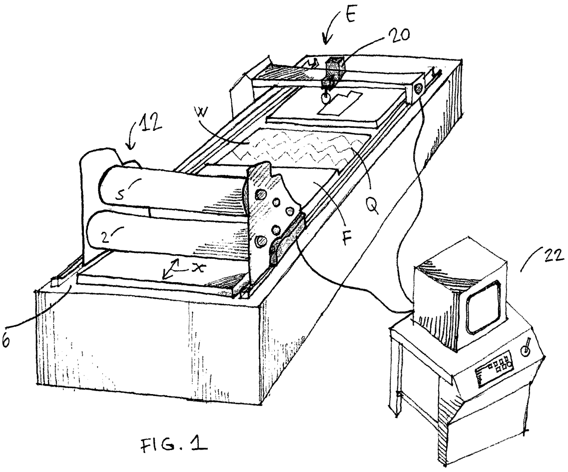

FIG. 1

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Description

Field of the invention

[0001] This invention relates the manufacturing of garments, upholstery and other items from fabric or other flexible sheet material. In particular, the present invention deals with an innovative method and apparatus for spreading and cutting flexible sheet materials from rolls or other supply of the same on to a work table preparatory to cutting or other operation.

Background of the invention

[0002] A process for fabricating products related to garments, upholstery and other sheet material includes a number of steps and utilizes complex machinery. Typically, the system has a flow line layout consisting of three stages, connected by a linear conveyor. Each stage corresponds respectively to a spreader, a cutting machine and an unloading stage, where a human operator picks cut-out pieces.
In the first stage the sheet material is spread one ply at a time to form a lay-up having a certain length. (Each ply spread has a different length thus implying that the length of the lay-up is equal to the length of ply or plies with the maximum length.) The spreader worktable is connected to the cutting table by a linear conveyor. The cutting stage consists in cutting out pieces in compliance with a pre-established layout, said cutting pattern.
Therefore, the cutting pattern outline the shapes of the parts to cut-out. Frequently, it is advantageous to form a single lay-up (i.e. a sequence of cutting patterns) with varying heights of spread plies for each cutting pattern, different typologies of sheet materials, i.e. different colored fabric. In the sequel, the area of lay-up corresponding to a single cutting pattern is referred to as cutting position.
A lay-up consists of a sequence of cutting positions each of them characterized by a stack of plies. Moreover, each cutting position joins at least one spreading operation with the contiguous cutting positions. The linear conveyor advances so that to bring in the cutting zone one cutting position at a time. Pieces related to a cutting pattern are obtained by means of a tool which penetrates into the lay-up while the sheet material is held against the table by suction.
The cutting tool is typically a knife and is moved according to the current cutting pattern. Downstream from the cutting out zone there is the unloading stage. To each shape of the cutting pattern corresponds a single piece or a stack of pieces cut out. In the unloading phase there is an operator designated to distinguish pieces cut out correctly, during the pick-up phase.

[0003] To optimize productivity in the manufacturing of a assigned quantity of parts, i.e. the workload, that must be delivered to the following operations within an assigned due date, the minimization of the workload make-span (i.e. the time between the starting time of the spreading operation of the first part and the end of the unloading operation of the last cutting position) may be considered as the main goal.
Given the workload of the machinery, in order to reach the goal two important contributors are: the ability to shorten the time spent by cut-out pieces in the unloading zone and the ability to maximize the length and height of each spread lay-ups , given both the spreader work-table length and the maximum number of plies that can be cut at once.

[0004] The first contributor is related to advances in fabric cutting technology and to those solutions that can be proposed to support the picking operator in order to distinguish in a correct manner shapes of the cutting pattern as well as different groups of layers in the lay-up. In US patent 6,521,074 it has been proposed a solution to the presence of off-cuts that are complementary respect to the shape of the cut-out pieces set.
Such off-cuts clutter up the unloading zone and they can complicate the identification of the pieces to be unloaded, in particular when at least some of the pieces are difficult to distinguish from the off-cuts. To overcome this difficulty, in US patent 6,521,074, a scaling film is applied over the surface of a stack, prior to the sucking phase. The scaling film is cut together with the sheet material.
The off-cuts of the scaling film are referred to as "skeleton". The skeleton is diverted from the path of sheet material in the unloading zone so as to be recovered automatically and separately from the cut-out pieces. The absence of the skeleton can make it easier to identify the pieces to be unloaded because they are the only portions of the sheet material that remain covered with the scaling film.
Another difficulty related to recognition of the cut-out pieces concerns the presence in the cutting pattern of similar shapes but in different sizes. This issue is typically encountered in clothing manufacturing, where similar shapes are related to the same article of clothing, but in different sizes. In US Patent 2,364,293, it has been proposed a solution to distinguish visually shapes.
In the cutting phase each shape is automatically labeled. Labels typically include information regarding part name, description and size as well as model identification and name.
The above solution is incomplete, if there exist "similar" articles sharing the cutting pattern but following different processing phases downstream the unloading phase. In clothing industry, this is true when the pieces cut-out are related to

article differing only in terms of fitting.

This issue is difficult to be managed in the spreading phase, since, in general, each cutting position in the lay-up could be characterized by a different vertical partitioning of plies. Therefore applying a separating film in the spreading phase, by means of standard spreader, might require a huge number of roll changes. Often the actual solution to this difficulty is to spread sheet material so that to cut out "similar" articles in different cutting positions.

Therefore in this case, the system performance, measured by the parameter make-span, are worsted.

[0005] The second contributor deals with solutions related to the planning of the spreading operations that determine the number of spread lay-ups, as well as the length and the height of each them. The solutions proposed in the state of art relate to the hardware optimization of the spreader. In particular, it has been made considerable progress toward decreasing the slowdown due to the set-up operations of the spreading phase. Therefore, in real-world applications characterized by a great variety of sheet materials, the spreader has been provided by automated apparatus for roll changes (XM3000 BKR).

Another setup operation is related to the overturning of the plies. Overturning operations are useful when the sheet material has a geometric design and there exist mirror cutting patterns. For example, in upholstery manufacture some articles might be the right or the left version of the same model, i.e. a sofa model requires either the right arm or the left one. In this case, left and right versions can be cut out at once, adopting the left version cutting pattern and overturning the plies related to the right version.

An example of automated mechanism to overturn rolls is (ST4000T). In absence of the cutting side the overlapping of mirror cutting patterns can take place without overturning ply in the spreading phase, but overturning cut out pieces during the unloading one. In this case, plies related to two mirror cutting patterns are stacked in a single cutting position and separated in the unloading phase.

Given the above automatisms, the overall system is only controlled by computer based on software written so that to aid an operator to compose the lay-up on the basis of the current work load. Given a number of parts to be produced, the daily system productivity performance is the result of the operator's ability to group parts to be produced in the minimum number of lay-ups, where each position is characterized by a number of spread plies as higher as possible.

From this discussion of the art state in automated apparatus for processing flexible sheet materials, it may be seen that even if a considerable progress has been made toward increasing efficiency, there remains an unmeet need for a system that provides an automated solution for distinguishing layer groups among plies stacked in each cutting positions and a system that automatically provides high system productivity for unpredictable combinations of product requests.

Indeed, there remains an unmeet need for a system operating method for efficiently completing unpredictable combinations of products which require a great variety of sheet materials and cutting patterns.

Brief description of the drawings

[0006] Other features and advantages of the invention appear from reading the following description given by way of non-limiting example and with reference to the accompanying drawings.

Fig.1 is a perspective view of an apparatus embodying the present invention and used in practicing the methods of the present invention.

Fig.2 is a simplified schematic illustration of cutting patterns performed by system in Fig.1, where Fig.2(a) shows a couple of mirror cutting patterns, whilst Fig.2(b)Fig.2(c) and Fig.2(d) are related to a symmetric cutting pattern.

Fig.3 is a side elevational view of a lay-up composed by apparatus in Fig.1.

Fig.4 and Fig.5 are a somewhat schematic fragmentary perspective and side elevational view of the apparatus shown in Fig.1.

Fig. 6 is side elevational view of a lay-up composed by apparatus in Fig.1, where the overturning operations involves mirror and symmetric cutting patterns.

Fig. 7 is a flow chart in accordance with the system operating method of the present invention.

Fig.8 side elevational view of a lay-up composed by apparatus in Fig.1, constrained to end all spreading operations at the same point on the worktable.

Fig.9 reports both side elevational view of two lay-ups composed by apparatus in Fig.1 and the schematic diagram illustrating the cutting job similarity in accordance with the method of Fig.7.

Detailed description of preferred embodiments of the invention

[0007] Turning now to Fig.1, a typical apparatus embodying the present invention and used in practicing methods of the invention is indicated by the reference E. The illustrated apparatus E consists of a sheet material supporting surface 16, a sheet material spreader 12 having a supply roll S and movable to and from longitudinally relative to the table to spread a ply F, as it is dispensed from the roll S and a rotary cutting device 20.

The system is provided by a controller 22 which sends and receives signals to the cutting device and the spreader. The controller includes a PC computer with sufficient memory and other peripheral hardware to perform the functions set forth herein.

The spreader 12 is provided by drive motors and other electromechanical devices widely used in the flexible sheet material manufacturing and designed to pay-off material from the roll S at linear rate, generally corresponding to the linear rate at which the sheet material is spread on the supporting surface. The spreader operates in response to command signals sent by the controller. Each spreading command corresponds to a distance D respect to the spreader zero position and a spreading length of L (so that D-L>0). Let us suppose that the length unit is millimeter. The distances D and (D-L) corresponds to the beginning and ending spreading positions on the supporting table 16, respectively. In response to the command signal a setup operation takes place, that is the spreader moves toward the right end, when the longitudinal movement ends, the distance between the spreader and the spreader zero position is D. Then the spreading operation begins when the spreader moves toward left and operates to pay-off the material on to the supporting surface. When the advancing spreader is at (D-L) mm from the left end of the supporting table 16, the sheet material is cut to separate the material spread on the supporting surface from the supply roll S. A suitable cutting mechanism (not shown) may be mounted on the spreader for this purpose. If a multi-plies lay-up is desired, the spreading mode hereinbefore described may be repeated to build a lay-up which includes a plurality of stacked plies of sheet materials.

Moreover, in order to exploit mirror cutting patterns, spreader is provided by an automatic mechanism to overturn the supply roll S. Fig.2(a) is a simplified schematic illustrations of two mirror cutting patterns. Hereinafter, given the cutting pattern symbol, the mirror feature is denoted by M (i.e. A and A_M are mirror cutting patterns).

The spreading operations of a lay-up might require set up operations, due to supply roll changes. Roll changes may be related to real applications where there are different typologies of sheet materials and each typologies is characterized by a set of variants. For example, in the case of cloth manufacturing and upholstery, variants are colour and/or design. Hereinafter the terms variant and colour will be considered as equivalent. Table I reports an illustrative example of products requests, each of them detailed in terms of cutting patterns, length of spreading operation, colours and quantity.

Fig.3 details a lay-up 100 corresponding to Table I, where dotted lines refers to overturned plies. There are three cutting positions, related to the cutting pattern CP_1,CP_2,CP_3. The cutting operations are scheduled from right to left, that is the right most position is the first one and the left most position is the last one. In each cutting position, at least one spreading operation is joined with contiguous positions. Table II details the command signals of spreading operations related to the lay-up 100 in Fig.3. The schematic picture in Fig.3 is not representative of a flexible sheet material. Indeed, as the spreading operations proceed, spread sheet material could encounter one or more stairs of plies (for example, the three spreading operations related to command signals 4 in Table II). The feasibility of the spreading operations can be compromised by too high stairs. Therefore, spreading a ply on one or more stairs is admissible if stairs do not exceed a threshold value. Unfeasible spreading operations due too high stairs can be overcome by splitting the spreading operations, i.e. command signals 4 in Table II are splitted into three command signals with D and L value equal to (200mm, 200 mm), (300mm, 100mm) and (350 mm, 50 mm), respectively.

Even if not shown in Fig.1, the spreader can be provided by automatic mechanism for supply rolls change (XM300 BKR). Immediately upon the completion of the lay-up spreading operations, the lay-up is transferred in the area of the cutting machine and the cutting activity is started. Cutting position are processed one at a time, that is the cutting device processes stacked plies according to the related cutting pattern.

[0008] The technological features, hereinbefore stated, are widely adopted in the art of automatic apparatus for manufacturing flexible sheet materials. The two main innovative aspects related to the present invention are: innovative solution for applying a separating film between groups of plies of the lay-up and an innovative operating method for composing lay-ups so that to complete in an efficient manner unpredictable combinations of products which require a great variety of sheet materials and cutting patterns.

The first goal of the present invention concerns a system that provides an automated solution for distinguishing groups of layers in a single cutting position. In particular, the system is provided by a spreader paying-off a film in order to separated plies belonging to the same cutting position that is efficient and does not increases sheet material spreading time. In Fig.4 and Fig.5, a typical apparatus embodying the present invention and used in practicing methods of the invention is indicated by the reference 12.

Table I

Color Requests				
Cutting Pattern	**White**	**Gray**	**Black**	**Lenght**
CP_1	8	3	-	**200 mm**
CP_2	3	2	-	**100 mm**

(continued)

Color Requests				
Cutting Pattern	**White**	**Gray**	**Black**	**Lenght**
CP_{2M}	3	-	-	**100 mm**
CP_3	6	1	3	**50 mm**

Table II

Command	Roll	D	L	Overturned	Number of runs
1	Gray	350 mm	350mm	No	1
2	Gray	3 00 mm	3 00 mm	No	1
3	Gray	200 mm	200 mm	No	1
4	White	350 mm	350mm	No	3
5	White	200 mm	200 mm	No	5
6	White	350 mm	50 mm	No	3
7	White	300 mm	100 mm	Yes	3
8	Black	350 mm	50 mm	No	3

[0009] The spreader 12 is provided by drive motors, a programmable controller 22 and the other electromechanical devices widely used in spreading flexible sheet material and designed to pay-off material from the roll S at a linear rate, generally corresponding to the linear rate at which the sheet material is spread on the supporting surface. A drive motor 46 receives command signal from controller 22 and drives the supply roll S to pay-off flexible sheet material. At least one feed roller is controlled for rotation around an axis parallel to the axis of the supply roll S, but preferably, and as shown in Fig.4 and Fig.5 the apparatus includes feed rollers 47, 48, 49. The feed rollers 47,48,49 are driven in timed relation to supply roll S and to each other by a drive mechanism 50, which receives command signals from controller 22 so that to spread out flexible sheet on the working table 16. A means is provided to move longitudinally the overall carriage, to overturn the sheet material and to separate the material spread from the supply roll S. The separation of the ply F prom the sheet material on the supply roll F takes place by means of solution widely used in spreading flexible sheet material, but preferably, and as shown in Fig.4 Fig.5, by the cutter 17. Since the details of such a carriage construction are not essential to an understanding of the present invention, the carriage structure will not be further described. Further and in accordance with the invention means are provided for spreading a film ply Q separating sheet material plies stacked upper and below the film ply Q. As the sheet material spreading operation, hereinafter referred as the main spreading operation, goes on in response to signals sent by controller 22 the supply roll 2 operates to unroll the separating film Q. A drive motor 52 receives command signal from controller 22 and drives the supply roll 2 to pay-off separating film. The feed rollers 3 and 4 are driven in timed relation to supply roll 2 and to each other by a drive mechanism 51 and functions to spread out separating film on the working table 16. During the film spreading operation, hereinafter referred as the secondary spreading operation, the bars 5 and 6 are opened. The bars 5 and 6 extend transversely of the spreader carriage and substantially across the entire width of the carriage so that when bars are closed the film is tighten between them along its entire width. A drive motor 53 receives command signal from controller 22 and drives the bars 5 and 6 in the opening and closing operations.
The separating film Q and the main sheet material F (e.g. the fabric) are simultaneously dispensed from two different supply rolls S and 2. For each main spreading operation there might be one or more secondary spreading operations. Indeed, the separating film can be dispensed on any combination of cutting positions covered by the concomitant main spreading operation. The secondary spreading operation means to separate two different groups of plies stacked one on each other in order to make, at the unloading phase, visually distinguishable the plies stacked below, from the ones stacked over the spread separating film ply. Said separating film ply can be spread during the first spreading operation of the upper stacked plies and below the sheet material ply concurrently spread, or during the last spreading operation of the lower stacked plies and on the sheet material ply concurrently spread. As shown in Fig.4 and Fig.5 it should be preferable to couple up the separating film spreading operation with the first main spreading operation of the upper stacked plies.
To obtain an efficient system for spreading the separating film, the sequence of operations necessary to spread the separating film is designed in the present invention in order to require neither the stop of the overall carriage nor the stop of the main spreading operation.

Preferably, and as shown in Fig.4 and Fig.5, feed roller 49 corresponds to the engagement point between the separating film Q and the main sheet material F. The separation of the spread film from the supply roll 2 is obtained by a tearing pattern set on the separating film Q. In practising methods for spreading film ply Q, the tearing pattern be chosen among those ones that enable a correct tearing operation. One possible choice is a zig-zag pattern and it is shown in Figure 4 as W. The idea is similar to the one adopted for block notes where sheets are tore accordingly to a fixed tearing pattern, typically a straight line. The idea is to pay-off the separating film by a tearing operation instead of a cutting one.

The separating film Q is provided by a equally spaced tearing patterns. A tearing operation consists of the following steps: bars 5-6 are closed and, simultaneously feed rollers 3-4 and supply roll 2 stop; feed rollers 47-48-49 continue to rotate, so that a tension force is applied along the part of separating film positioned between bars 5-6 and feed roller 49. This tearing operation allows an immediate separation of the spread film from the supply roll 2 and it requires to stop neither the carriage nor the main spreading operation.

At the end of each tearing operation, the two edges of only one tearing pattern has been separated: one ending the film wound on the supply roll 2 and one ending the dispensed film ply. The distance between bars 5-6 and the feed roller 49 is set in order to make feasible both the tearing operation and the joining operation between the film and the sheet material that will take place in correspondence to the beginning of next film spreading operation. Preferably, and as shown, bearings 60 extend transversely of the spreader carriage and substantially across the entire width of the carriage so that the edge of the separating film wound on the supply roll 2 is correctly positioned for starting a new film spreading operation.

When a new film spreading operation is started, the bars are re-opened and the film feeding activity can be started, by re-starting the rotation of feed rollers 3, 4 and the supply roll 2. Each film spreading operation is size-dependent. In particular it is required that the film ply covers the corresponding cutting positions in a significant manner. There is no need that the length and the width of the sheet material ply equals those of the separating film ply, i.e. the film ply can be longer or/and shorter than the corresponding sheet material ply. Indeed, the main goal is that each separating film ply significantly covers the corresponding cutting positions and, during the unloading phase, there is no ambiguity between the cutting positions covered by the film ply and the contiguous ones.

Another approach is to dispense a separating film ply as long as the concomitant sheet material one. In this way the separating film covers as many contiguous cutting positions as the concomitant sheet material ply does. At the unloading phase, a work note, or any other suitable communication mean solution, can be used to detail to the human operator which separating plies have to be considered in each cutting positions (for example in the second cutting position, the second group of stacked plies is limited by the third and sixth film plies). The main advantage of this alternative solution consists in the opportunity to separate from the corresponding supply rolls both the film ply and the sheet material at the same time.

The second goal of the invention is to provide a method for operating an automatic apparatus E in a manner that achieves low make-span irregardless of the mix of product requests, that is the workload.

The processing time of each lay-up is obtained by the overall cutting time and the overall spreading time. Therefore, low make-span is obtained when the overall cutting time as well as the overall spreading time are minimized. Since cutting patterns are pre-assigned, the lower the overall number of cutting positions are, the lower the overall cutting time is. The overall spreading time is minimized if the number of spreading operations are minimized. This is true because of the acceleration during spreading phase (i.e. spreading one 2L length ply requires less time then spreading two different L length plies). Moreover, joining the spreading operations of several cutting positions decreases the number of roll changes as well as the number of overturning operations. In the viewpoint of make-span optimization, there are two key features: cutting patterns partitioning in to three groups, and an optimization algorithm oriented to compose lay-ups.

The proposed operating method consists of two key feature. The first key feature includes partitioning cutting patterns into a number of groups accordingly to the symmetry property respect to ply overturning.

All cutting patterns are defined respect to one of the two ply sides and called the cutting side. The ply is overturned if the upper ply side is not the cutting side. The cutting patterns are separated into three distinct groups defining if the ply overturning is feasible and if it requires or not a concomitant cutting pattern overturning. Fig.2 reports illustrative examples. The first group of cutting patterns (Symmetric-type) consisting of all those cutting patterns indistinguishable from its overturned version and where a ply overturning operation is feasible and requires no cutting pattern overturning operation. Fig.2(b) represents the pieces cut-out when the cutting side is the one characterized by a geometric design. Fig.2(c) reports the pieces cut-out when the ply is overturned. Fig.2(d) details Fig.2(c) respect to the opposite side. The second group (Mirror-type) consisting of pair of cutting patterns ((A, A_M)), where one is the overturned version of the other and the first cutting pattern (A) is adopted to obtain shapes of cutting pattern A_M when the ply is overturned respect to cutting side. Vice versa the second cutting pattern (A_M) is adopted to obtain shapes of cutting pattern A when the ply is overturned respect to cutting side. See Fig.2(a) for an example. The third group (Asymmetric-type) comprises all cutting patterns except those in said first group and said second group. It should be understood that all cutting patterns have to be considered as asymmetric if the sheet material sides are undistinguishable and are both suitable for cutting. In particular, each couple of mirror cutting patterns is exhaustively represents by only one of them, i.e. the cutting pattern **A.** Indeed, the cut-out pieces related to the cutting pattern $\mathbf{A_M}$ are overturned in the unloading phase. In this case the system operating method organizes the spreader activity so that to apply in the corresponding cutting positions the separating film between the plies related to and the plies related to $\mathbf{A_M}$**.** In all other cases, the stated groups help spreading and cutting time optimization since the ply overturning is allowed for the first and second grouping. Overturning plies in the second group helps to reduce the number of cutting positions: cutting patterns A and A_M can be cut out in the same cutting position. At the same time, the overturned ply spreading operation could be exploited to cover groups of contiguous cutting positions where there are a symmetric-type cutting patterns as well as a mirror cutting-patterns. In this way, set up time due to overturning operations is decreased. The cutting pattern partitioning can be exploited in order to reduce the time spent to spread plies of a lay-up. The lay-up 101 in Fig.6 is an illustrative example where cutting patterns CP_1 and CP_3 are symmetric and asymmetric respectively, whilst the cutting pattern CP_2 is mirror type. The overturned plies in CP_2 cutting position are due to a not null requests for the CP_{2M} cutting pattern. The overturned plies spreading operations can be exploited to cover both the CP_2 cutting position. This is possible for the symmetric property of CP_1.

In the present invention, the second key feature of the system operating method is an optimization algorithm minimizing both the number of cutting positions and the number of spreading operations. Fig.7 is a flow chart detailing the decision-making steps executed by the system operating method in order to compose a lay-up.

[0010] Let H_{max} denote the maximum number of plies stackable in a cutting position. If there exist cutting patterns with H_{max}-overflowing demands, minimizing the number of cutting positions as well as the number of spreading operations might become conflicting objectives. Indeed, given the generic H_{max}-overflowing cutting pattern *i* (i=1,..,N) the computation of the minimum number of cutting positions related to it, i.e. P_i, is a straightforward arithmetic operation (see (111) and (112) and Table III). The minimization of the number of spreading operations might require a number of cutting positions greater than P_i.

Since the system performance are almost influenced by the number of cutting positions, a trade-off is rejected and the highest priority is given to the optimization of cutting positions. Indeed, the apparatus E is typically provided by a lay-up buffer between the spreading and the cutting stages. In this case, in the production there might be more than one lay-up in process. Consequently, the cutting machine and the spreader work in parallel. Since the cutting phase is the last one, the system performance are almost influenced by the cutting time: the number of cutting positions must be minimized, firstly (the first step 80 in Fig.7). Table III reports a notation related to technological constraints and product requests.

Table III

Symbol	Description
H_{max}	Maximum number of stackable plies
L_{max}	Spreader work-table length
N_S	Number of symmetric cutting patterns
N_A	Number of asymmetric cutting patterns
N_M	Number of pairs of mirroring cutting patterns
$N = (N_S + N_A + N_M)$	Number of distinct cutting patterns
K	Number of distinct colours
$i \in [1,..,N_S] \cup [(N_S+1),..,(N_A+N_S)] \cup \cup [(N_S+N_A+1),.., (N_S+N_A+N_M)]$	Cutting pattern index i=1,..,N
(i, i_M)	Pair of mirroring cutting patterns(i=N_A+1,..,N)
K	Colour index (k=1,..,M)
C_{ik}	Number of requests for cutting patterns i-th with colour k. (k=1,..,M i=1,..,N)
$C_{iM}k$	Number of requests for i_M that is the mirror cutting pattern related to i-th with colour k. (k=1,..,M i=N_A+1,..,N)
P_i	Number of cutting positions of the i-th cutting pattern (i=1,..,N)
P	Maximum number of cutting positions in a lay-up
j	Cutting positions index j=1,.,P

[0011] The minimum number of cutting positions P_i is determined as follows

$$P_i = \left\lceil \frac{\sum_{k=1}^{K} C_{ik}}{H_{\max}} \right\rceil \quad i \in [1,..,N_A] \qquad (111)$$

$$P_i = \left\lceil \frac{\sum_{k=1}^{K} \left(C_{ik} + C_{i_M k}\right)}{H_{\max}} \right\rceil \quad i \in [N_A + 1,..,N] \qquad (112)$$

where $\lceil \cdot \rceil$denotes *the minimum integer value greater or equal.*

[0012] Cutting patterns with a P_i value greater than 1 will be denoted as H_{max}-overflowing cutting patterns.
Once determined the P_i's values, i.e. the minimum number of cutting positions, the second step 81 in Fig.7, and, the third step 82 in Fig.7, are devoted to determine the minimal cutting job set (i.e. for each cutting pattern i is determined how to arrange the coloured requests in P_i positions, each arrangement will correspond to a cutting job) and to sequence its elements in order to minimize the number of spreading operations. In accordance with the present invention the second step 81 determines, for each of the P_i cutting jobs, how many requests of the C_{ik} demand has to be included, i.e. how many k-th colour plies are included. There are two constraints to be satisfied: each cutting position will not include more than H_{max} plies and the overall sum of k-th coloured plies included in the P_i cutting jobs will be equal to C_{ik}. The output of the second step 81 is the minimal set of jobs to be processed by the cutting device, i.e. the cutting job, and the corresponding similarity sequencing matrix. Each matrix element assigns a "pair values", i.e. distance between jobs, based upon colour similarity. Indeed, each possible pairing of jobs receives a similarity pair value, providing a measure of how many spreading operations could be joined together in each cutting job pair. In alternative, each pair of jobs can be valued by a measure of their dissimilarity, i.e. how many spreading operations cannot be joined together. The third step 82 exploits the similarity (dissimilarity) matrix in order to solve a sequencing problem, subject to L_{max} constraint and product requests C_{ik} constraints.
The objectives of the second step 81 and the third step 82 are the same: minimizing the number of spreading operations. This goal is obtained through the maximization of job sequence similarity or the minimization of job sequence dissimilarity. Since the shared optimization goal the second step 81 and the third step 82 can be simultaneously tackled in a unique framework. However, due to the combinatorial nature of the considered optimization problems there might be the need to execute each step separately accordingly to the hierarchical order shown in Fig.7. An object of the present invention is an optimal algorithm as well as a near-optimal algorithm to solve combinatorial aspects related to the second step 81 and the third step 82.
Since these decisional steps involves mathematical operations which can be cast in widely different but mathematically equivalent expressions, the scope of the present invention is defined in terms of equivalent of a particular expression. Those skilled in the art will recognize that equivalent formalizations can use different number of steps, different combinations of operations with steps, and different expressions for operations. Mathematical technique can resolve unambiguously the question of mathematical equivalence of method for the purpose of determining the scope of the present invention.
Given the products request the system controller elaborates the lay-up according to the flowchart of Fig.7. The resulting lay-up is converted into a list of command signals and sent to the spreader and the cutting device. The complete system, from proper lay-up determination to actual manufacturing, can operates completely under computer control, essentially free from human intervention.

Formalization: general lay-up composition problem

[0013] Given the spreader work table length L_{max}, the maximum number of cutting positions in the lay-up is:

$$P = \left\lfloor \frac{L_{\max}}{\min(L_i)} \right\rfloor \quad (113)$$

[0014] Once determined the minimum number of cutting position (i.e. P_i 's value), a preferred formalization of the lay-up composition program defines a cutting job sequence as one that maximizes (minimizes) colour commonality (dissimilarity) between successive jobs. The expressions (114)-(132) report a formalization for the maximization of the total commonality of the out-put sequence. Symbols exploited in expressions can be drawn on Table III.

For notational need, each cutting pattern i (i=1,..,N) has been indexed respect to a mirror one i_M ($i_M=1_M,..,N_M$). If the i_M cutting pattern does not exist (i.e. i is an Asymmetric or a Symmetric one) a null value is assigned to the corresponding parameters and decision variables.

Each integer X's decision variable represents the number of plies to be spread at position j for each cutting pattern (i or i_M) and for each colour k. Symbols "-" and "+" determine if the ply overturning has to take place or not, respectively.

Each binary Y's decision variable equal 1 if at position j the cutting pattern i (or i_M) will be cut out. Otherwise the binary variables equal 0.

Each T decision variable represents the similarity between the cutting pattern placed at position j and the cutting pattern placed at position j+1. The similarity is detailed in terms of the k-th coloured plies overturned (i.e. T_{jk}^-) or not overturned (i.e. T_{jk}^+).

Each Z's decision variable represents the dissimilarity between the cutting pattern placed at position j and the cutting pattern placed at position j+1. The dissimilarity is detailed in terms of the k-th coloured plies overturned (i. e. Z_{jk}^-) or not overturned (i. e. Z_{jk}^+).

$$Max\ F = Max \sum_i \sum_k \left(T_{jk}^+ + T_{jk}^- \right) \qquad (114)$$

$$\sum_i \sum_k \left(X_{ijk}^+ + X_{ijk}^- + X_{i_M jk}^+ + X_{i_M jk}^- \right) \le H_{\max} \qquad (115)$$

$$\sum_j \left(X_{ijk}^+ + X_{ijk}^- \right) \le c_{ik} \qquad (116)$$

$$\sum_j \left(X_{i_M jk}^+ + X_{i_M jk}^- \right) \le c_{i_M k} \qquad (117)$$

$$\sum_k \left(c_{i_M k} + c_{ik} \right) - \sum_j \sum_k \left(X_{ijk}^+ + X_{ijk}^- + X_{i_M jk}^+ + X_{i_M jk}^- \right) \le H_{\max} \left(P_i - \sum_j \left(Y_{ij} + Y_{i_M j} \right) \right) \qquad (118)$$

$$\frac{\sum_k \left(X_{ijk}^+ + X_{ijk}^- \right)}{\sum_k C_{ik}} \le Y_{ij} \qquad (119)$$

$$\frac{\sum_{k}\left(X^{+}_{ijk}\right)}{\sum_{k} C_{ik}} \leq Y_{ij} \tag{110}$$

$$\frac{\sum_{k}\left(X^{+}_{i_M jk}\right)}{\sum_{k} C_{i_M k}} \leq Y_{i_M j} \tag{111}$$

$$\frac{\sum_{k}\left(X^{-}_{ijk}\right)}{\sum_{k} C_{ik}} \leq Y_{i_M j} \tag{112}$$

$$\frac{\sum_{k}\left(X^{-}_{i_M jk}\right)}{\sum_{k} C_{i_M k}} \leq Y_{ij} \tag{113}$$

$$\sum_{i} Y_{ij} + Y_{i_M j} \leq 1 \tag{114}$$

$$\sum_{j}\sum_{i} L_i Y_{ij} + L_i Y_{i_M j} \leq L_{\max} \tag{115}$$

$$\sum_{i}\left(X^{+}_{ijk} + X^{+}_{i_M jk}\right) - \sum_{i}\left(X^{+}_{i(j+1)k} + X^{+}_{i_M(j+1)k}\right) \leq Z^{+}_{jk} \tag{116}$$

$$\sum_{i}\left(X^{-}_{ijk} + X^{-}_{i_M jk}\right) - \sum_{i}\left(X^{-}_{i(j+1)k} + X^{-}_{i_M(j+)1k}\right) \leq Z^{-}_{jk} \tag{117}$$

$$\sum_{i}\left(X^{+}_{ijk} + X^{+}_{i_M jk}\right) - Z^{+}_{jk} = T^{+}_{jk} \tag{118}$$

$$\sum_{i}\left(X^{-}_{ijk} + X^{-}_{i_M jk}\right) - Z^{-}_{jk} = T^{-}_{jk} \tag{119}$$

$$X^{+}_{i_M jk} = X^{-}_{i_M jk} = 0 \quad i=1,\dots,N_S+N_A \tag{120}$$

$$X^{-}_{ijk} = 0 \quad i = N_S+1,..,N_A \tag{121}$$

$$X^{+}_{ijk} \geq 0 \ \textit{integer} \tag{122}$$

$$X^{+}_{i_M jk} \geq 0 \ \textit{integer} \tag{123}$$

$$X^{-}_{ijk} \geq 0 \ \textit{integer} \tag{124}$$

$$X^{-}_{i_M jk} \geq 0 \ \textit{integer} \tag{125}$$

$$Z^{-}_{jk} \geq 0 \tag{126}$$

$$Z^{+}_{jk} \geq 0 \tag{127}$$

$$T^{-}_{jk} \geq 0 \ \textit{integer} \tag{128}$$

$$T^{+}_{jk} \geq 0 \ \textit{integer} \tag{129}$$

$$Y_{i_M j} \in \{0,1\}, \tag{130}$$

$$Y_{ij} \in \{0,1\} \tag{131}$$

$$Y_{i_M j} = 0 \quad i=1,\dots,N_S+N_A \tag{132}$$

[0015] Expression (114) maximizes the total similarity between positions in the determined lay-up. An alternative optimization goal can be the minimization of the total dissimilarity between positions in the determined lay-up.

[0016] Expressions (115) state that for each position the number of stacked plies cannot exceed H_{max}.
Expressions (116)-(117) state that for each cutting pattern i and for each colour k the number of allocated plies have not to exceed product request C_{ik}.
Expressions (118) assure that the number of cutting positions is minimized according to P_i values determined at the first step 80.
Expressions (119) state the relationship between X's and Y's variables for the symmetric and asymmetric cutting patterns.
Expressions (110) and (111) state that, for each cutting pattern i, plies have to be overturned or not if at each position j it has been placed the cutting pattern i_M (i.e. Y_{iMj}=1) or the cutting pattern i (i.e. Y_{ij}=1).
The same considerations apply to each cutting pattern i_M by means of expressions (111) and (113).

Expressions (114) state that for each position j at most one cutting pattern can be placed.

Expressions (118) state that the lay-up length cannot exceed the spreader work-table length, L_{max}. Expressions (116)-(117)-(118)-(119) state the relationship among *Z's, T's* and *X's* decision variables.

Expressions (120)-(132) state that there does not exist a mirror cutting pattern for asymmetric and symmetric cutting patterns.

Expressions (121) state that overturning operations cannot be applied to Asymmetric-type cutting patterns.

Expressions (122)-(131) state the nature of decision variables.

In the state of art there are apparatus for spreading and cutting sheet material, where all spreading operations are constrained all to end at the same point of the work table (typically at the spreader zero position). This means that the difference D-L of each command spreading signal must be equal to zero. In these system the heights of cutting positions in a single must have a not increasing profile from the left most cutting position (i.e. the last cutting position) to the right most one (i.e. the first cutting position). The lay-up 102 in Fig.8 is an illustrative example. This technological constraint can be embedded in the formulation of (114)-(132) by adding the set of linear inequalities (133)-(134):

$$\sum_{i=1}^{N}\sum_{k=1}^{K} X_{ijk}^{+} \leq \sum_{i=1}^{N}\sum_{k=1}^{K} X_{ij+1k}^{+} \quad \forall j = 1,..,N-1 \quad (133)$$

$$\sum_{i=1}^{N}\sum_{k=1}^{K} X_{ijk}^{-} \leq \sum_{i=1}^{N}\sum_{k=1}^{K} X_{ij+1k}^{-} \quad \forall j = 1,..,N-1 \quad (134)$$

[0017] The second and third decisional steps(i.e. the second step 81 and the third step 82) of Fig. 7 can be recast using the described mathematical formalism.

[0018] **The second step 81.** The X's decision variable values determine unambiguously the similarity matrix for cutting jobs included into the current lay-up.

[0019] The X's values determine position by position the number of plies to be spread each of them characterized in terms of colour and overturning operation. The Expression (118) guarantee that each cutting pattern i will be processed exploiting no more than P_i cutting positions. In particular the left hand side represents for each cutting pattern the number of plies not allocated in the current lay-up. The right hand side computes the maximum number of plies that can be allocated in further lay-ups without violating the P_i cutting position constraint. Expressions (115) represent the H_{max}—constraint. Expressions (116) and (117) guarantee that the *X's* values are consistent with product requests. Expressions (116)-(119) model the concept of similarity between positions.

[0020] **The third step 82.** The Y's decision variable values detail the cutting job sequence related to the current lay-up. Expressions (119)-(115) take into account the mirror cutting pattern concept, the overturning operation, the L_{max}-constraint. Given the cutting job sequence the expression (114) expresses the related similarity value. The max operator represents the search algorithm valued on the basis of Expression (114). Maximizing the sequence similarity is equivalent to minimize the number of spreading operations.

Implementation issues

[0021] The implementation details related to lay-up composition deal with the computational complexity inherent the adopted solution algorithm. If an optimal solution is required, given the formalization in (111)-(132) or an equivalent one, the lay-up composition can be obtained by means of an optimal solution algorithm. Computational issues might guide the choice between a general purpose optimal algorithm for mixed-integer linear programs (a commercial software may be ILOG Cplex 9.0) and a special purpose optimal solution algorithm. If the optimal approach is unfit, i.e. too long time is required to obtain at least a good feasible solution, heuristic methods can be adopted. The heuristic method can tackle the second step 81 and the third step 82 by means of a decomposition approach. In the following some approaches are presented as examples.

Dillenberger, Ch., L.F. Escudero, A. Wollensak and W. Zhang in "On practical resource allocation for production planning and scheduling with period overlapping setups", European Journal of Operational Research 75, 275-286 1994, propose the Fix-and-relax methodology as decomposition method to solve a large scale mixed integer programming (MIP). The approach decomposes the original problem into a number of smaller MIP sub-problems. The limited size of these sub-problems allows using exact methods for their solution, which would be impossible for the entire problem, in a reasonable amount of time. The number and the size of the sub-problems define the computational burden and the solution quality of the heuristic procedures. The Fix and Relax approach is based on a partition of the integer decision variable set. The method requires as many iterations as the determined sub-set are. Moreover the sequence by which the sub-problem are solved and the variables partition has to be defined so that to guarantee the determination of a feasible solution. To each subset is associated a mixed integer programming sub-problem, fixing variables related to previously solved sub-problems, declaring integer variables related to the current sub-problem and relaxing the integral constraints related to the remaining integer variable subsets. The defined sub-problem is solved optimally and the integer variable values are used for the fixing related to the next sub-problem. The final solution is determined by the variable values provided by solving the last sub-problem (including those fixed by precedence steps).

The main issues of this approach are: the partitioning policy and the sub-problem feasibility. A decomposition approach for the lay-up composition problem, a position based-partition policy can be considered: each partition sub-set consists of variables related to contiguous cutting positions. For example if there are two subsets V_1, V_2 such that $|V_1| + |V_2| = P$: the integer variables indexed from $j=1$,.., $|V_1|$ are related to V_1, integer variables indexed from $j=|V_1+1|$,.., $|P|$ are related to V_2. There exists no matter about sub-problem feasibility, since fixing decision variables position by position results in a lay-up consisting at least of one position.

Another decomposition approach concerns dealing with the decisional the second step 81 and the third step 82, one at time.

[0022] The combinatorial nature of the second step 81 is due to: requests for multi-coloured H_{max}— overflowing cutting patterns, i.e. there are different colour requests for H_{max}—overflowing cutting patterns; and/or requests for symmetric cutting patterns and for mirror cutting patterns. In both cases the main issues is to value between any pair of cutting positions. However given the hereinbefore mentioned requests, the similarity matrix as well as the dissimilarity matrix cannot be determined a-priori respect to the job sequence (the job sequence will be computed in the next step 82).

The second step 81 can be tackled by any heuristic approach oriented to maximize some average measures of similarity matrix elements (or minimize some average measures of dissimilarity matrix elements).

Other approaches are to deal with H_{max}-overflowing cutting patterns by : relaxing the H_{max} constraint and considering a unique cutting job for each H_{max}-overflowing cutting pattern. Given the cutting jobs, the feasibility respect to the relaxed constraint is recovered by post-processing procedure in the third step 82.

In particular, even relaxing the H_{max} constraint, the similarity matrix could not be unambiguously determined due to requests of mirror cutting patterns and symmetric cutting patterns. That is, the overturning operations of a symmetric cutting job is determined only when the job is inserted into a sequence. The sequencing problem to be solved at the third step 82 is a historical set-up sequence dependent problem. This problem is typically encountered in Flexible Manufacturing System and it is often formalized as a generalization of the Travelling Salesman Problem as stated by Tang, C. and Denardo, E. in "Models Arising from Flexible Manufacturing Machine, Part I: Minimization of the Number of Tool Switches" Operation Research Vol. 36, No. 5, pp.767-777,1988 and by Laporte,G. Salazar-Gonzalez, J., Semet, F. in "Exact algorithms for the job sequencing and tool switching problem". The classical TSP stipulates that a salesperson must visit a sequence of cities one at a time, never visiting the city twice. The optimization goal is to minimize the total distance travelled.

The cutting job set can be mapped on an undirected graph G(N,V), where N is the set of nodes and V the set of edges. Each node corresponds to a cutting job and is characterized by a cost coefficient, i.e. the cutting pattern length. Edge has a gain coefficient corresponding to sequencing the two end nodes. Each gain coefficient is equal to deterministic value if any end node is a symmetric job. On the contrary, if at least one end node is a symmetric job the edge cost is a function of the actual sequence or it is an estimated value of such function value. Given the graph G, the algorithm determines a job sequence by selecting a subset of edges, such that to form a chain of nodes, not exceeding the L_{max} threshold. Moreover, for each pair of mirror cutting patterns there exits a cluster of nodes in G, i.e. there are two nodes in G representing the two alternative way of processing the mirroring cutting job. Only one of node in the cluster can be included in the output sequence. Under this respect, the solution is made of a sequence of node cluster, each cluster consisting of one or two nodes.

The stated sequencing problem must take into account the resource constraints implied by the L_{max} constraint. The algorithm designed to solve this sequencing problem can be derived by any algorithm designed for the generalized-TSSP+1 problem, the problem of finding a maximum profit cluster sequence in a graph under a one additional constraint. The adopted algorithm can be taken from literature and further properly modified in order to take into account that some similarity matrix elements (those related to symmetric job) is a function of the actual sequence. Feillet,D., Dejax,P., Gendreau, M. in "Travelling Salesman problem with profits: an overview" provide an overview for the TSSP+1. The lay-ups 103 and 105 in Fig.9(a) and Fig.9(b) illustrate that it is not possible to determine a priori the similarity between the symmetric cutting job of the second position (labelled CP_2) and the mirroring cutting job of the first position (labelled CP_1) (see Table I for product request details of CP_1, CP_2, CP_3). The cutting job labelled CP_3 and CP_4 are asymmetric. The graph 104 and 106 in Fig.9a and Fig.9b report the similarity values to be considered: the sequencing value of CP_1 and CP_2 cannot be determined a-priori to the determination of the overall sequence.

Claims

1. A method for an apparatus designed to spread and to cut flexible sheet material wound on a supply roll, said apparatus provided by means for depositing one or more plies of sheet material onto a working surface table in order to automatically compose a lay-up consisting of stacked plies, said plies deposited by a spreader which performs a size-dependent movements in one and opposite direction longitudinally of said working surface with arbitrary starting and ending points; said spreader provided by means for depositing and detaching one or more plies from said sheet material supply roll in order to automatically form a single lay-up with varying heights, said spreader provided by means to spread automatically overturned plies; said apparatus provided by means to hold the lay-up or one portion of it against the table by suction; said apparatus provided by a tool passing through the stacked plies in order to cut-out sets of predetermined shapes, called cutting patterns, according to a sequence of cutting sessions, each said cutting session **characterized by** one and only one cutting pattern and one and only one cutting area, called cutting position, each said cutting position related to one and only one cutting session; said apparatus provided by means for unloading pieces cut-out; the method comprising:

o depositing automatically one or more plies of a separating film at different heights of said sheet material lay-up, each film ply separating lower stacked plies from the upper stacked plies;
o depositing said separating film ply during the sheet material spreading operation without stopping nor reducing the speed of the sheet material spreader;
o said separating film wound on a supply roll and pre-pricked off along a predetermined pattern, called tearing pattern, that extends transversely across the entire width and that is repeated periodically longitudinally the film roll.

2. The method according to claim 1, wherein the method further comprises:

o depositing automatically a separating film ply covering one or more contiguous cutting positions, in order to make, at the unloading phase, visually distinguishable the plies stacked below, from the ones stacked over the spread film ply;
o spreading said film ply either during the first spreading operation of the upper stacked plies and below the sheet material ply concurrently spread, or during the last spreading operation of the lower stacked plies and on the sheet material ply concurrently spread;
o depositing during the concomitant sheet material spreading operation one or more separating film plies, each of them covering one or more contiguous cutting positions;
o depositing a separating film ply over one or more contiguous cutting positions, so that the covered area points out with no ambiguity which are the cutting positions where the upper and lower stacked plies has to be distinguished at the unloading phase;
o detaching the separating film from the film supply roll by a cutting operation or by applying two opposite tension forces along said tearing patterns; said tearing operation allowing an immediate separation of the spread film from the supply roll and requiring to stop neither the carriage movement nor the main spreading operation;
o cutting out shapes according to a predetermined cutting pattern by means of a tool passing through the separating film plies and the sheet material plies stacked in each cutting positions.

3. A method of operating an apparatus as set forth in claims 1 and 2 that is capable of machining a plurality of jobs, each one requiring both one different cutting operation according to a cutting pattern defined respect to one of the two ply sides and called the cutting side, and a set of spreading operations **characterized by** a plurality of sheet material variants, the method comprising:

o partitioning the cutting patterns into three separate groups defining if the ply overturning is feasible and if it requires a concomitant cutting pattern overturning, where the first group of cutting patterns (Symmetric-type) consisting of all those cutting patterns indistinguishable from its overturned version and where a ply overturning operation is feasible and requires no cutting pattern overturning operation; the second group (Mirroring-type) consisting of pair of cutting patterns **$((A, A_M))$**, where one is the overturned version of the other and the first cutting pattern **(A)** can be adopted to obtain shapes of cutting pattern **A_M** when the ply is overturned respect to cutting side of **A**; viceversa the second cutting pattern **(A_M)** can be adopted to obtain shapes of cutting pattern **A** when the ply is overturned respect to cutting side of A_M; the third group (Asymmetric-type) comprising of all cutting patterns except those in said first group and said second group;
o operating the apparatus so that each spreading operations depositing overturned ply can cover one or more cutting positions if and only if the related cutting patterns do not belong to the third group of said three groups;

o operating the apparatus so that each spreading operation depositing overturned ply can cover one or more cutting positions if and only if the related cutting patterns belong to the first or second group of said three groups.

4. A method of operating an apparatus as set forth in claim 1 that is capable of arranging in one or more lay-ups a plurality of product batches, each **characterized by** a different cutting pattern and a set of product requests each of said requests **characterized by** a sheet material variant and a number of items to be produced; the method composing a single lay-up one at time, as set forth in claim 1,2 and 3, as a sequence of cutting positions by comprising:

o determining, for each batch or equivalently for each cutting pattern, the minimum number of cutting positions, computed as the minimum integer value greater or equal to the ratio between the total number of requests related to the considered batch and the maximum number of stacked plies that can be cut out at once by the cutting tool, said H_max;
o partitioning product batches into two groups, where the first group, called H_max overflowing group, comprises those batches, **characterized by** a total number of product requests greater than said H_max; the second group comprises all batches except those in said first group;
o determining a first sequence of cutting positions, as said in claim 1, 2 and 3, each of them **characterized by** a cutting pattern, and said sequence determined so that its length does not exceed the length of spreader working surface, said L_max;
o defining a cutting job for each cutting position in the first sequence by assigning a plurality of items, chosen among those ones to be cut out according to the cutting pattern assigned to said cutting position, the number of said items determined so that said H_max value is not exceeded and the minimal number of cutting positions for the considered cutting pattern is not increased;
o calculating said first sequence value by assigning a pair value to each pair of cutting jobs in the first sequence, the pair value being a monotonic function of how many spreading operations could be joined together in the sequence taking into account the three groups partition set forth in claim 3;
o determining the sequence of command signals to be executed by the apparatus of claim 1, in order to compose and to cut out the determined sequence of cutting jobs;
o causing the apparatus to compose the lay-up and to cut-out the stacked plies in each cutting position in the order of the determined cutting job sequence;
o decreasing the number of items requested in each said product batches according to the determined cutting job sequence.

5. A method as set forth in claim 4 where in the method further comprises:

o if the monotonic function is not decreasing, finding the optimal cutting job sequence by repeating the determining, the defining and the calculating steps for each plurality of different possible cutting job sequences and selecting the sequence which has the largest sequence value;
o if the monotonic function is not increasing, finding the optimal cutting job sequence by repeating the determining, the defining and the calculating steps for each plurality of different possible cutting job sequences and selecting the sequence which has the smallest sequence value.

6. A method of operating an apparatus as set forth in claim 1,2,3,4 and 5, that decomposes the decision problem of determining a cutting job sequence, sub-optimal respect to a monotonic function as said forth in claims 4 and 5, into a sequence of smaller decision sub-problems, each of said sub-problem determining a portion of the sequence of cutting jobs.

7. A method of operating an apparatus as set forth in claim 1,2,3,4,5 and 6, that decomposes the decision problem of determining a cutting job sequence, sub-optimal respect to a monotonic function as said forth in claims 4 and 5, into three consecutive steps comprising:

o assigning a pair value to each pair of product batches, as said in claims 4 and 5, the pair value being a monotonic function of how many spreading operations could be joined together in each product batch pair;
o arranging the product batches in a sequence determined by evaluating a generalized sub-tour travelling salesman problem with knapsack constraints, with the sequencing value determined in the previous step and properly modifying the travelling salesman problem algorithm in order to determine unambiguously the sequencing cost of each batch related to a symmetric cutting pattern as set forth in claim 3;
o determining for each position of the sequence evaluated in the arranging step, the plurality of items determined , as said in claim 4, so that the H_max value is not exceeded and the minimal number of cutting positions for the

considered cutting pattern is not increased.

Amended claims in accordance with Rule 86(2) EPC.

1. A method for using an apparatus designed to spread and to cut flexible sheet materials wound on a supply rolls, the method comprising:

○ depositing one or more plies of sheet material (F) onto a working surface table (16) in order to automatically compose a lay-up consisting of stacked plies;
○ depositing automatically one or more plies of a separating film (Q) at different heights of said sheet material lay-up, each film ply separating lower stacked plies from the upper stacked plies;
○ depositing said separating film ply during the sheet material spreading operation without stopping nor reducing the speed of the sheet material spreader;
○ said separating film wound on a supply roll (2) and perforated along a predetermined pattern, called tearing pattern (W), that extends transversely across the entire width and that is repeated periodically longitudinally the separating film roll;
○ cutting out sets of predetermined shapes, called cutting patterns, by means of a tool (20) passing through the separating film and the sheet material;
○ said cutting phase organized according to a sequence of cutting sessions;
○ each said cutting session **characterized by** one and only one cutting pattern and one and only one cutting area, called cutting position;
○ unloading cut-out pieces downstream from the cutting-out table.

2. The method according to claim 1, wherein the method further comprises:

○ depositing automatically a separating film ply covering one or more contiguous cutting positions, in order to make, at the unloading phase, visually distinguishable the plies stacked below, from the ones stacked over the spread film ply;
○ spreading said film ply either during the first spreading operation of the upper stacked plies and below the sheet material ply concurrently spread, or during the last spreading operation of the lower stacked plies and on the sheet material ply concurrently spread;
○ depositing during the concomitant sheet material spreading operation one or more separating film plies, each of them covering one or more contiguous cutting positions;
○ depositing a separating film ply on one or more contiguous cutting positions, so that the covered area points out with no ambiguity which are the cutting positions where the upper and lower stacked plies has to be distinguished at the unloading phase;
○ detaching the separating film from the film supply roll by a cutting operation or by applying two opposite tension forces along said tearing patterns; said tearing operation allowing an immediate separation of the spread film from the supply roll and requiring to stop neither the carriage movement nor the main spreading operation;
○ cutting out shapes according to a predetermined cutting pattern by means of a tool passing through the separating film plies and the sheet material plies stacked in each cutting positions.

3. A method of operating an apparatus as set forth in claims 1 and 2 that is capable of machining a plurality of jobs, each one requiring both one different cutting operation according to a cutting pattern defined respect to one of the two ply sides and called the cutting side, and a set of spreading operations **characterized by** a plurality of sheet material variants, the method comprising:

○ partitioning the cutting patterns into three separate groups defining if the ply overturning is feasible and if it requires a concomitant cutting pattern overturning, where the first group of cutting patterns (Symmetric-type) consisting of all those cutting patterns indistinguishable from its overturned version and where a ply overturning operation is feasible and requires no cutting pattern overturning operation too; the second group (Mirroring-type) consisting of pair of cutting patterns (**(A, A_M)**), where one is the overturned version of the other one and the first cutting pattern **(A)** can be adopted to obtain shapes of cutting pattern **(A_M)** when the ply is overturned respect to the cutting side of **A;** viceversa the second cutting pattern **(A_M)** can be adopted to obtain shapes of cutting pattern **A** when the ply is overturned respect to cutting side of A_M; the third group (Asymmetric-type) comprising of all cutting patterns except those in said first group and said second group;
○ operating the apparatus so that each spreading operations depositing overturned ply can cover one or more

cutting positions, if and only if the related cutting patterns do not belong to the third group of said three groups;
○ operating the apparatus so that each spreading operation depositing overturned ply can cover one or more cutting positions if and only if the related cutting patterns belong to the first or second group of said three groups.

4. A method of operating an apparatus as set forth in claim 1 that is capable of arranging in one or more lay-ups a plurality of product batches, each **characterized by** a different cutting pattern and a set of product requests each of said requests **characterized by** a sheet material variant and a number of items to be produced; the method composing a single lay-up one at time, as set forth in claim 1,2 and 3, as a sequence of cutting positions by comprising:

○ determining, for each product batch or equivalently for each cutting pattern, the minimum number of cutting positions, computed as the minimum integer value greater or equal to the ratio between the total number of requests related to the considered batch and the maximum number of stacked plies that can be cut out at once by the cutting tool, said H_max;
○ partitioning product batches into two groups, where the first group, called H_max overflowing group, comprises those batches, **characterized by** a total number of product requests greater than said H_max; the second group comprises all batches except those in said first group;
○ determining a first sequence of cutting positions, as said in claim 1, 2 and 3, each of them **characterized by** a cutting pattern, and said sequence determined so that its length does not exceed the length of spreader working surface, said L_max;
○ defining a cutting job for each cutting position in the first sequence by assigning a plurality of items, chosen among those ones to be cut out according to the cutting pattern assigned to said cutting position, the number of said items determined so that said H_max value is not exceeded and the minimal number of cutting positions for the considered cutting pattern is not increased;
○ calculating said first sequence value by assigning a pair value to each pair of cutting jobs in the first sequence, the pair value being a monotonic function of how many spreading operations could be joined together in the sequence taking into account the three groups partition set forth in claim 3;
○ determining the sequence of command signals to be executed by the apparatus of claim 1, in order to compose and to cut out the determined sequence of cutting jobs;
○ causing the apparatus to compose the lay-up and to cut-out the stacked plies in each cutting position in the order of the determined cutting job sequence;
○ decreasing the number of items requested in each said product batches according to the determined cutting job sequence.

5. A method as set forth in claim 4 where in the method further comprises:

○ if the monotonic function is not decreasing, finding the optimal cutting job sequence by repeating the determining, the defining and the calculating steps for each plurality of different possible cutting job sequences and selecting the sequence which has the largest sequence value;
○ if the monotonic function is not increasing, finding the optimal cutting job sequence by repeating the determining, the defining and the calculating steps for each plurality of different possible cutting job sequences and selecting the sequence which has the smallest sequence value.

6. A method of operating an apparatus as set forth in claim 1,2,3,4 and 5, that decomposes the decision problem of determining a cutting job sequence sub-optimal respect to a monotonic function as said forth in claims 4 and 5, into a sequence of smaller decision sub-problems, each of said sub-problem determining a portion of the sequence of cutting jobs.

7. A method of operating an apparatus as set forth in claim 1,2,3,4,5 and 6, that decomposes the decision problem of determining a cutting job sequenc, sub-optimal respect to a monotonic function as said forth in claims 4 and 5, into three consecutive steps comprising:

○ assigning a pair value to each pair of product batches, as said in claims 4 and 5, the pair value being a monotonic function of how many spreading operations could be joined together in each product batch pair;
○ arranging the product batches in a sequence determined by evaluating a generalized sub-tour travelling salesman problem with knapsack constraints related to the maximum length L_max, with the sequencing value determined in the previous step and properly modifying the travelling salesman problem algorithm in order to determine unambiguously the sequencing cost of each batch related to a symmetric cutting pattern as set forth in claim 3;

○ determining for each position of the sequence evaluated in the arranging step, the plurality of items determined ,as said in claim 4, so that the H_max value is not exceeded and the minimal number of cutting positions for the considered cutting pattern is not increased.

8. An installation for automatically depositing on to a working surface (16) separating film (Q) plies and flexible sheet material (F) plies, at different heights; the installation comprising a supply roll (S) for the flexible sheet material (F) and a supply roll (2) for the separating film (Q), feed means (47), (48), (49) for unroll the flexible sheet material (F) and the separating film (Q) synchronously on to the supporting surface W, the feed rollers (49) where sheet material (F) engages the separating film (Q); means to separate simultaneously the film ply and the sheet material ply from the supply roll (S) and (2) by a cutting operation; two bars (5) and (6) positioned beside the feeds rollers (49), before the engagement point of (Q) and (F); said bars (5) and (6) to be closed when it is needed to be deposit, on to the working surface (16), a film ply shorter than the concomitant sheet material ply; detaching said shorter film ply, by applying a tension force on one of the tearing patterns falls between the bars (5) and (6) and the fed rollers (49), when said bars are closed and the feed rollers (49) do not stop.

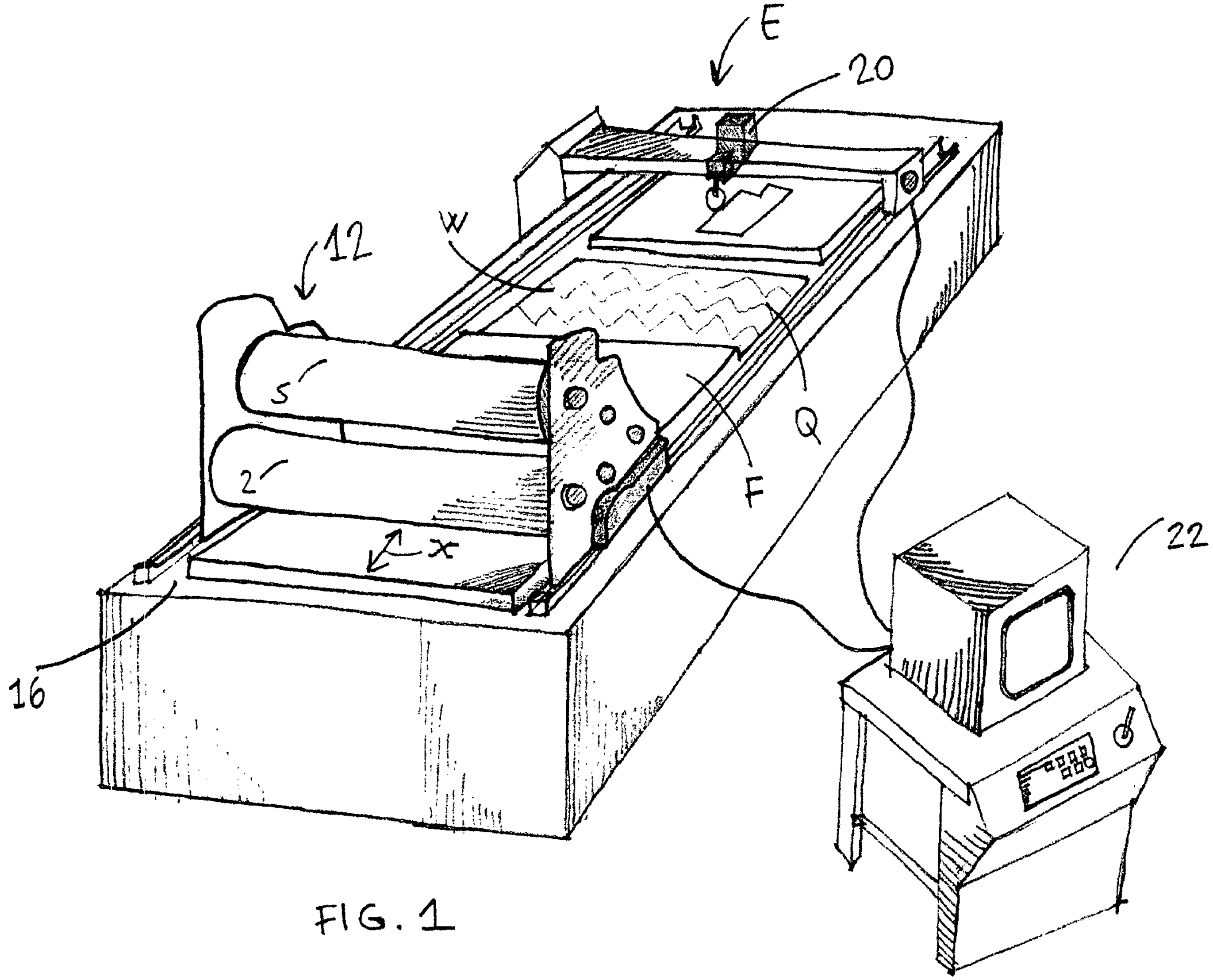

FIG. 1

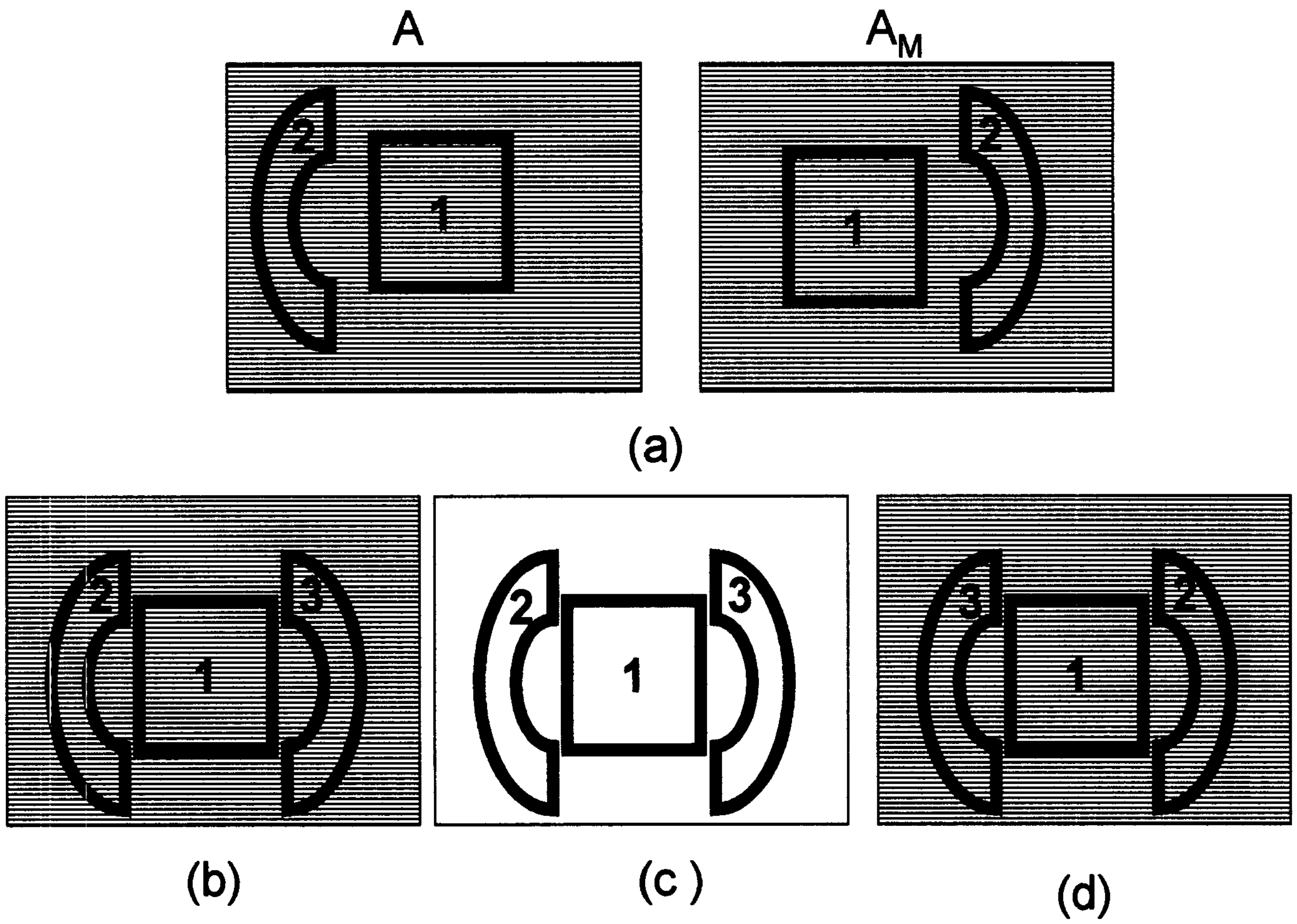

Fig.2

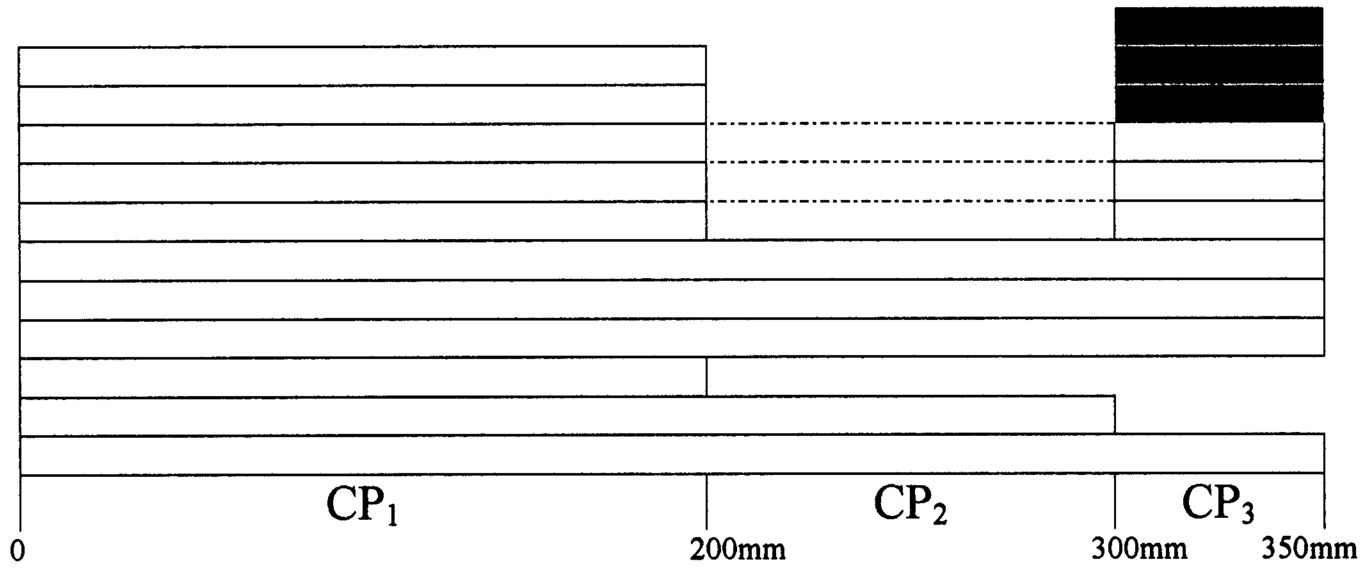

Fig.3

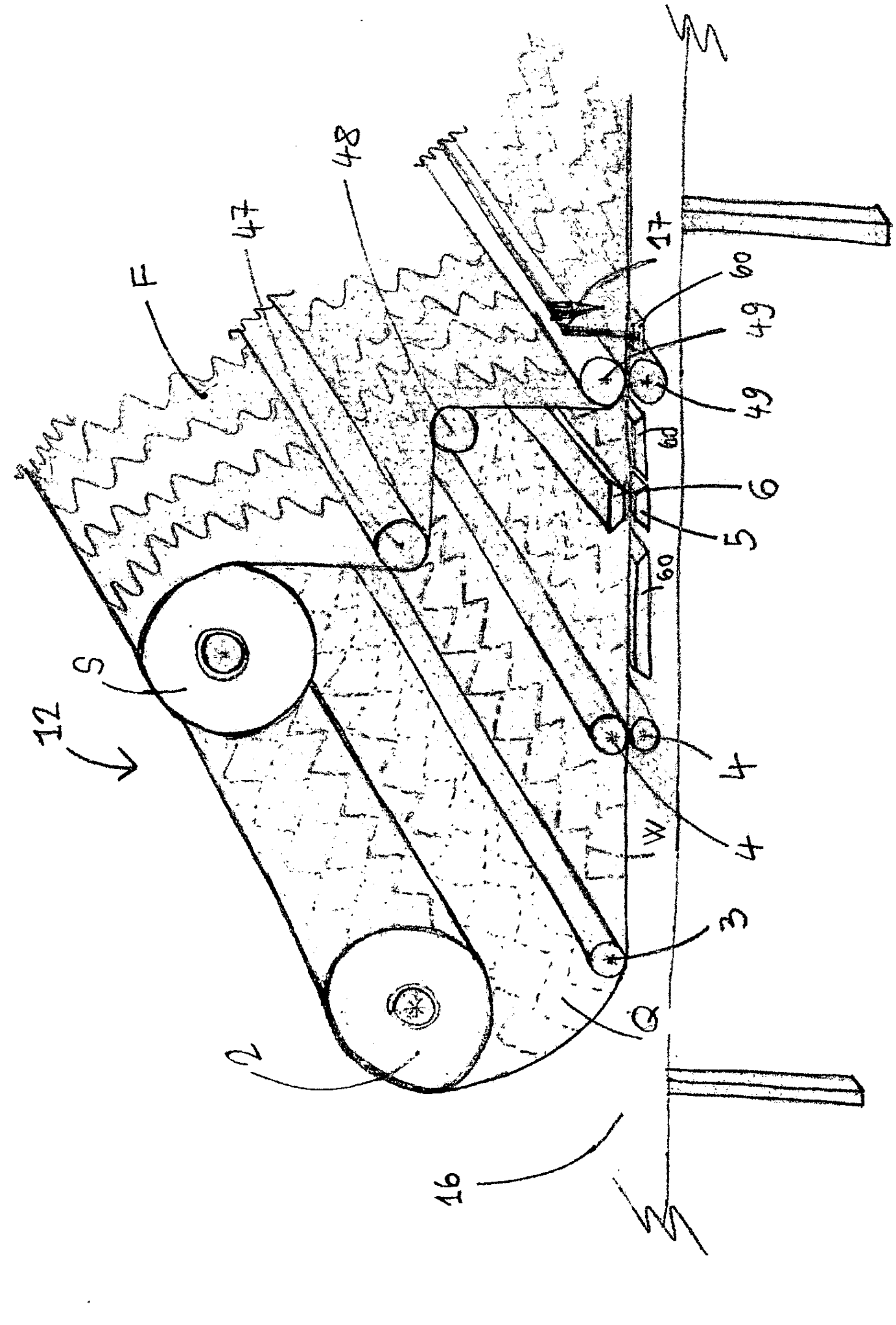

FIG. 4

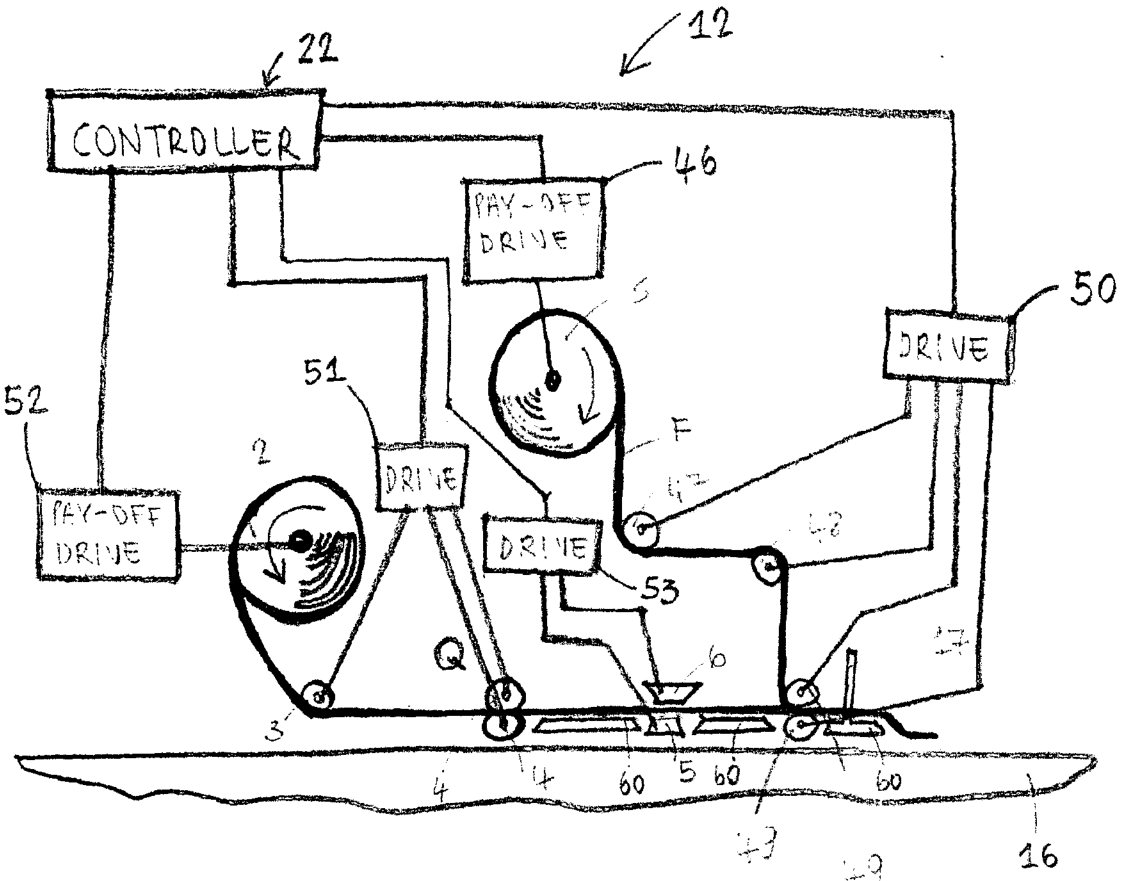
12
22
CONTROLLER
46
PAY-OFF DRIVE
50
DRIVE
52
PAY-OFF DRIVE
51
DRIVE
2
5
F
47
48
DRIVE
53
Q
6
3
4
4
60
5
60
43
60
49
47
16

FIG. 5

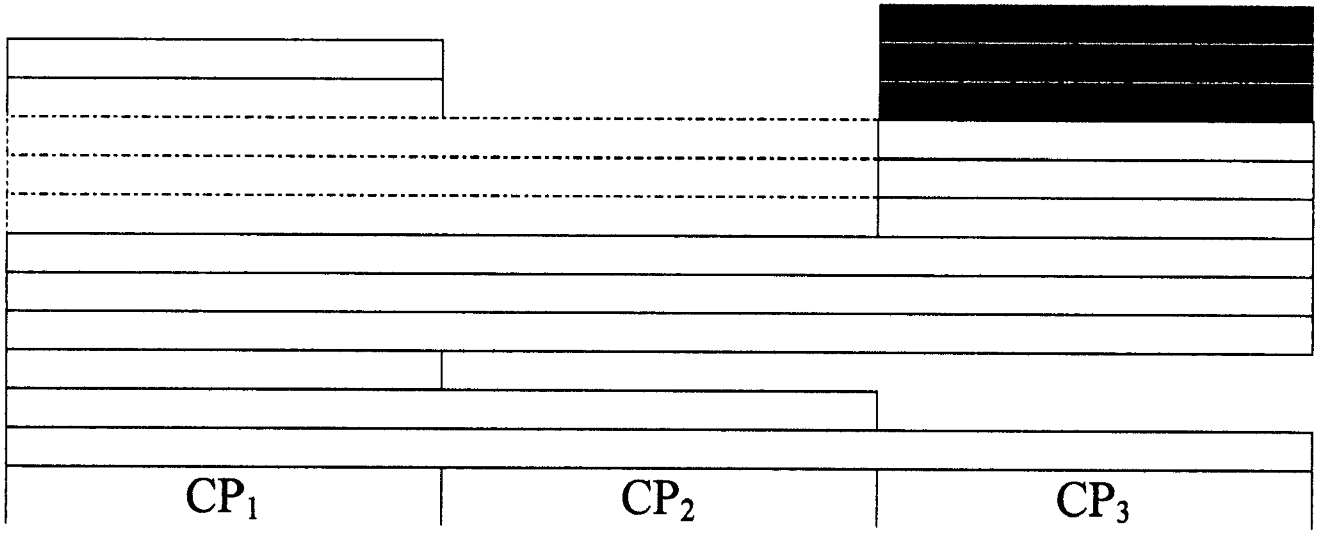

Fig.6

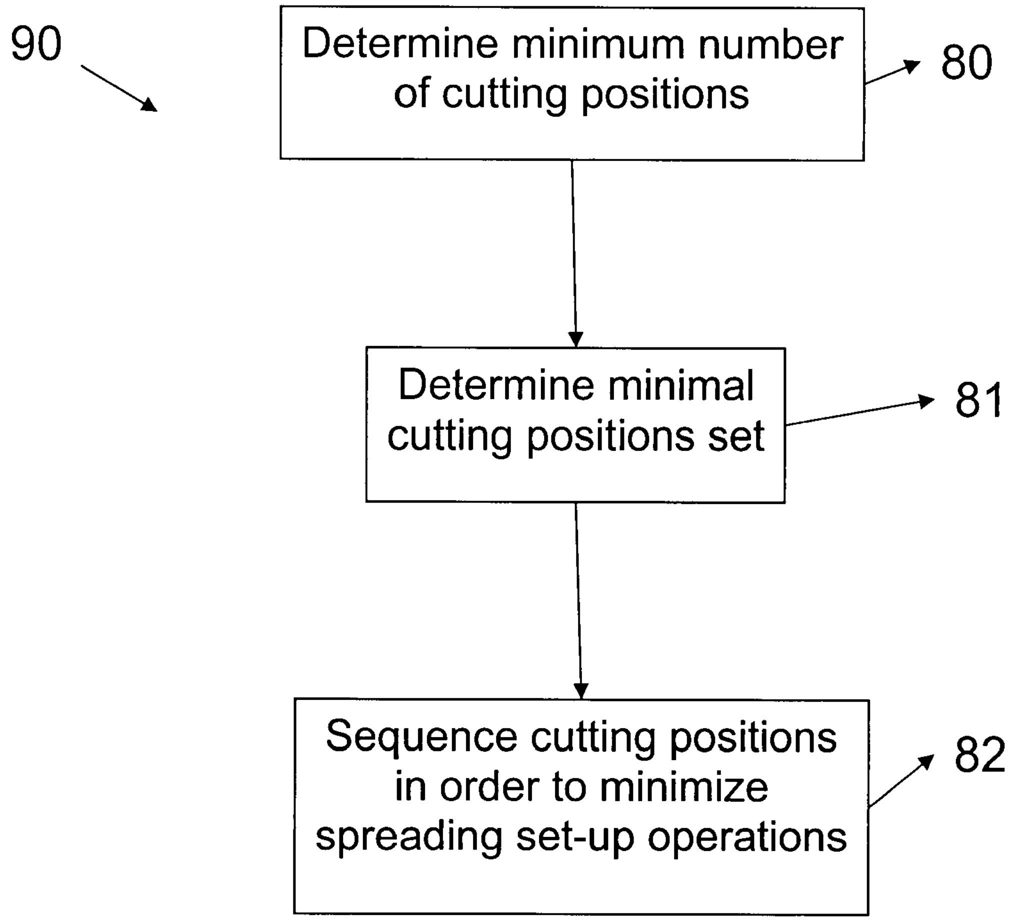
90
Determine minimum number of cutting positions
80
Determine minimal cutting positions set
81
Sequence cutting positions in order to minimize spreading set-up operations
82

Fig. 7

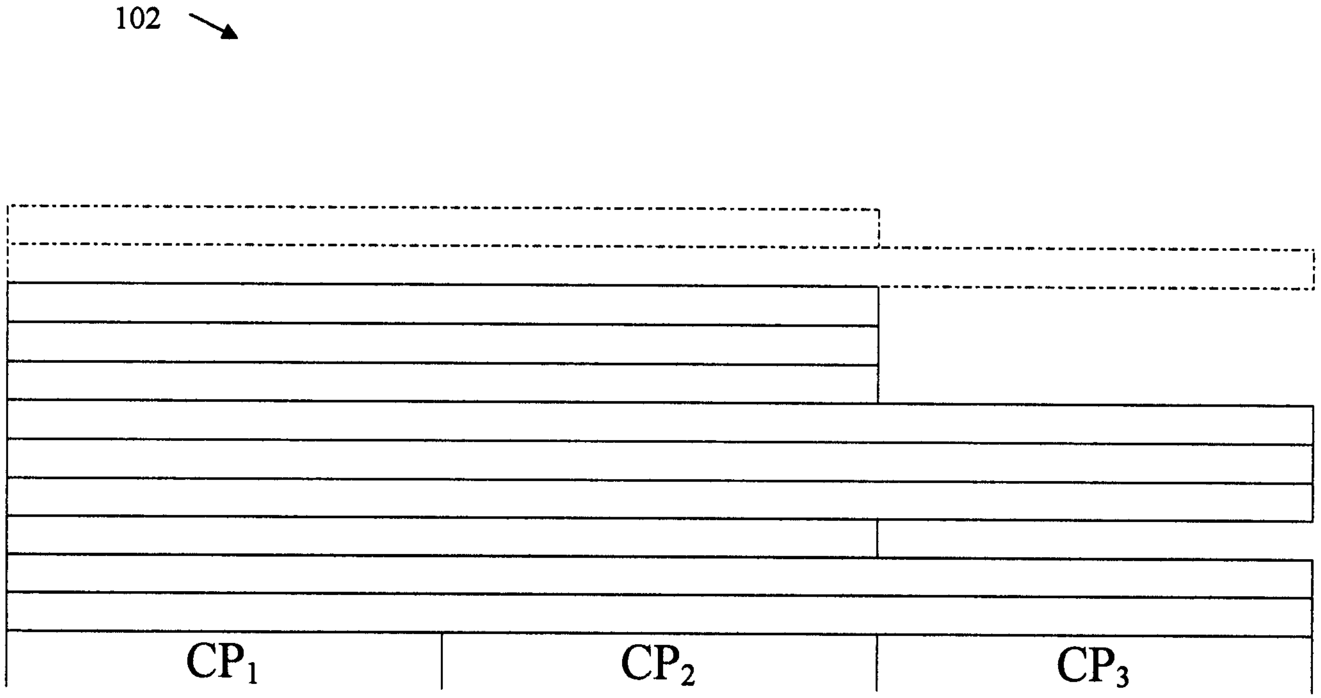

Fig.8

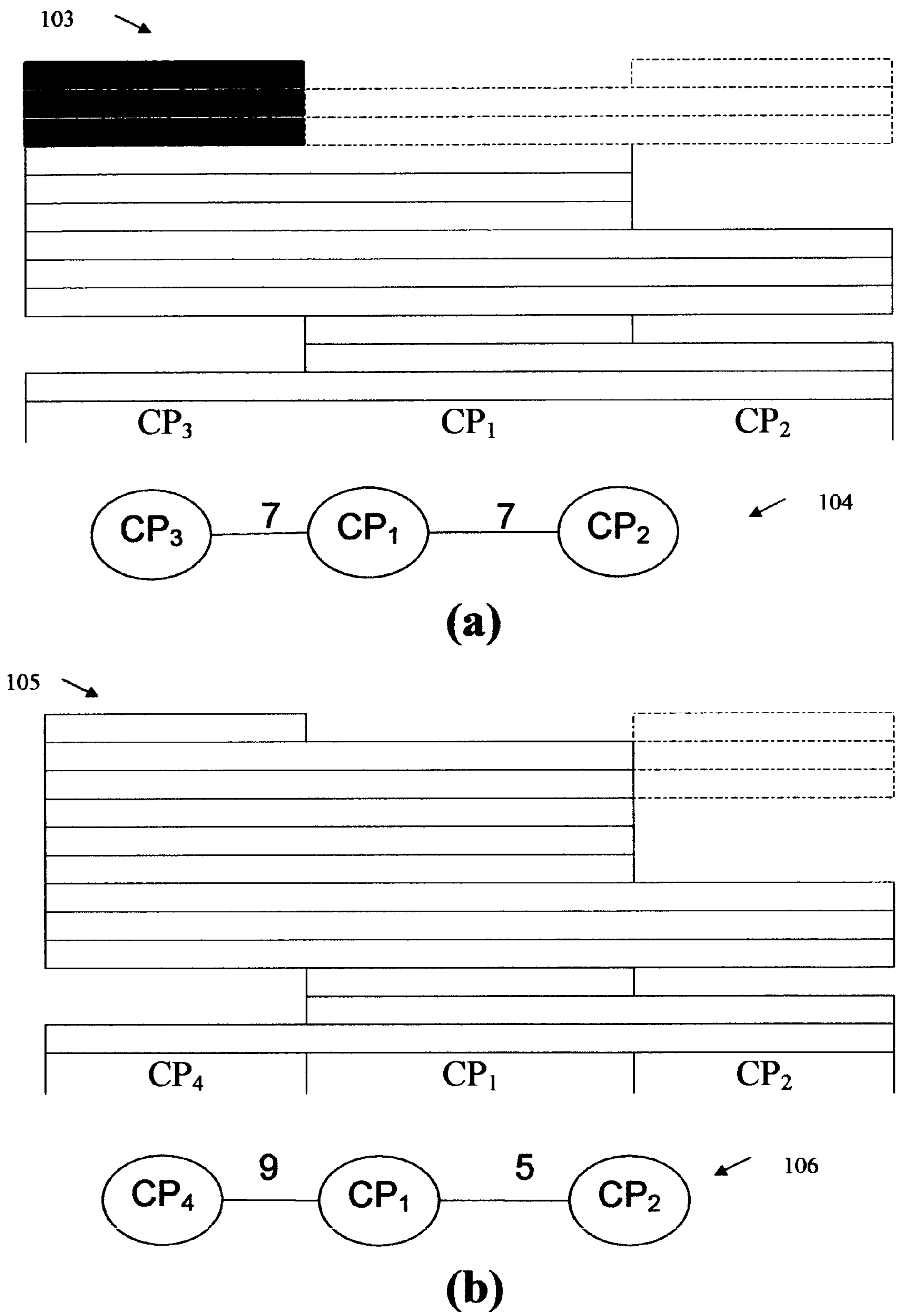
103
CP3
CP1
CP2
CP3
7
CP1
7
CP2
104
(a)
105
CP4
CP1
CP2
CP4
9
CP1
5
CP2
106
(b)

Fig. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 05 42 5513

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	DE 199 06 304 A1 (BRAUN, HANS PETER) 17 August 2000 (2000-08-17) * column 1, line 26 - line 50; figures 1,2 *	1-7	B26D5/00 B26F1/38 A41H43/00 B65H45/00
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A	US 5 024 862 A (FRANK ET AL) 18 June 1991 (1991-06-18) * figures 1,5 *	1-7	

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B26D
B26F
A41H
B65H

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	30 November 2005	Wimmer, M

CATEGORY OF CITED DOCUMENTS

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1

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30-11-2005

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