An improved device (11) and process for creating a lining in a bore, transfers strip wrapped in overlapping spiral fashion about a mandrel (4) to the bore wall such that the edge-to-edge relation of the spirally-wrapped strip (21) is maintained from the mandrel (4) to the bore wall. Adhesive is applied to the strip surface during wrapping thereof on the mandrel (4). The invention provides a new bore with a thin, strong, corrosion resistant lining over a preselected portion of its length that is substantially pressure tight internally and externally and leak proof thus permitting substantial reuse of the lined bore.
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BACKGROUND OF THE INVENTION

Underground bores such as oil wells, pipelines, gas mains and the like are susceptible to cracking or rupturing due to corrosion of the existing casings, shifts in the ground, and external pressures which can crush or rupture the bores. These losses of integrity can cause the fluids passing through them to seep into the environment which can cause contamination to water tables as well as presenting fire hazards in the cases of gas mains and the like.

Likewise, certain situations require the closure of previous perforations or other man-made openings in casings, tubings or the like. In some cases repairs are required to bores that have been damaged by wear or abrasion by moving components. Also, the relining of a bore to present a different material interface within the bore can be extremely advantageous.

To repair these bores various elaborate methods have been developed which generally involve inserting a new section of pipe or liner into the bore to be repaired and placing the new lining in the appropriate section and then expanding the lining so that it then fills or covers the gap.
These methods for repairing the casings generally have been limited to fairly small areas because of the difficulties encountered in handling long liners, and have largely been unsuccessful due to the problem of "springback" of metallic tubular materials when expanded internally. Springback prevents establishment of a good seal against the well casing.
SUMMARY OF THE INVENTION

The method for relining downhole casings and the like which is provided for by this invention involves spiral wrapping of a resilient flexible strip lining material about a special downhole tool to the length of the patch or repair to be made. The tool with wrapping attached is inserted into a bore of slightly larger internal diameter than the overall diameter of the wrapped tool to the location of the patch or repair to be made. One end of the wrapping material is then expanded from the tool tightly against the internal wall of the bore to be relined and the wrapping is then unwound progressively off the tool until, by its resiliency, it tightly engages the walls of the bore to be lined to the full length of the wrapping. The other end of the wrapping material is then expanded from the tool and against the bore wall.

It is desirable for one of the alternating layers of material to be comprised of a settable resinous material such as an epoxy to ensure adhesion and a complete seal between the various layers of lining materials.

Once the lining material is in place, the mandrel is then withdrawn and the bore is returned to use.

By the term "bore" it is meant any cylindrical opening or the like within a surface to include oil wells, water mains, gas mains, pipelines, electrical conduits or the like.
By "lining material" it is meant any form of flexible material having sufficient resiliency or elasticity to uncoil in the manner described. This material can be various sheet metal such as steel having a thickness of between 0.004 inches and 0.030 inches with a preferable thickness of 0.010 inches or dictated by the bore to be repaired. For example, for oil wells the use of beryllium copper is preferred because of its corrosion resistance and high strength. In other cases, various plastics reinforced with glass fiber or carbon fiber, etc., may be employed. Special stainless steels and nickel-base alloys may be of use. It is to be borne in mind that the interior of an oil well is a hostile environment containing chlorides, hydrocarbons, sometimes sulfides, etc. Many metallic materials simply disintegrate in such an environment. Beryllium copper, such as Alloy 190, having a yield strength of about 100,000 to about 125,000 psi and a modulus of $18.5 \times 10^6$ is particularly well suited to the service.
FIGURE 1 shows a machine for wrapping lining material about the downhole tool at the well head.

FIGURE 2 shows the tool when it is first placed into the bore.

FIGURE 3 shows the lower packer assembly in its inflated position with the lining material unwrapped up to the upper packer.

FIGURES 4 and 5 show, in cross-section, the lower packer assembly.

FIGURES 6 and 7 show, in cross-section, of the upper packer assembly.

FIGURE 8 depicts the arrangement of the wrapping material strip at the initiation of the wrapping operation.

FIGURE 9 depicts the thin sheet material which may be formed into a collar about the downhole tool to fasten the wrapping material thereto, and FIGURES 10 and 11 depict the sheet of FIGURE 9 after it has been wrapped into a collar.

FIGURES 12A through 12E depict a supplemental safety device for preventing undesired loss of the tool down the well.

SUBSTITUTE SHEET.
FIGURE 13 depicts the mandrel of the invention in the extended, locked position.

FIGURE 14 depicts the mandrel of the invention in the unlocked, telescopied position.

FIGURE 15 depicts the hydraulic piston for actuating the lower push-rod in the lowermost mandrel segment.

FIGURE 16 depicts in plan view the improved wrapping machine of the invention; and

FIGURE 17 depicts in plan view a more detailed view of the wrapping machine.
DETAILED DESCRIPTION OF THE INVENTION

In carrying the invention into practice, the downhole tool is first prepared. The tool comprises an upper packer assembly, a lower packer assembly, which incorporates a release device such as a shear pin operable from the surface to permit rotation of the upper packer with respect to the lower packer upon demand, with the two packer assemblies being spaced apart by a mandrel section of desired length having in mind the length of patch to be effected in the well to be repaired. The mandrel section itself may be made of sections of hollow steel such as tubing steel screwed together to form the requisite length. Each of the packer assemblies has a hollow core, with a check valve being provided at the lower end of the lower packer assembly. The downhole tool is suspended in the well on hollow tubing string steel, permitting transmission of hydraulic commands to the tool from the surface.

The completed downhole tool with spirally-wrapped strip material therearound is depicted in Figure 2 of the drawing as being suspended in a well adjacent a failed place in the well casing to be patched. As shown in Figure 2, the tool comprises a mandrel 4 having a lower packer assembly 2 and an upper packer assembly 5. Lining material 21 is shown wrapped about the mandrel in Figure 2. A centralizer 56 may be employed at the bottom end of the tool. The tool is shown suspended from tubing string 3. Other essential features of the downhole tool include circulating means for fluids which
are controlled by commands from the surface. These will be described in connection with Figures 4 through 7.

Turning now to Figure 1, which depicts a machine 11 mounted on the well head of a well to be patched in accordance with the invention, it will be seen that the machine consists of a frame 12 bearing a fixed crosshead 13 and a movable crosshead 14. The movable crosshead is raised and lowered by lead screw 23 which is powered by reversible power head 16 through pins 26. Upper and lower collets, designated 28 and 24 respectively, are mounted on the frame about upper port 17 and on movable crosshead 14. Collets 24 and 28 are preferably of the type which are normally closed and require actuation to be opened. Material payoff assembly 27 is preferably mounted concentrically about lead screw 23 and is powered by the same power head 16 which powers lead screw 23. Material payoff means 27 bears a plurality of axles 15 adapted to hold spools of strip 30. Brake means 19 prevents rotation of material payoff means 27 when the movable crosshead 14 is being raised. For this purpose also, drive means 16 is connected to material payoff means 27 by ratchet means so that material payoff means 27 is powered only when lead screw 23 is descending. Upper and lower ports 17 and 18 in the frame are aligned so that tool 22 can be passed completely therethrough. The collets 24 and 28 are controlled such that at least one of them is always closed to grip the tool while the wrapping operation is in progress.
To initiate the wrapping operation, tool 22 is passed downwardly through machine 11 to the point at which the lower packer assembly 2 reaches the wrapping area, i.e., the area at which the strip material 21 wound on spools 30 can reach tool 22 at the angle preset by the axles 15 on which spools 30 are mounted. The strip material is fastened to tool 22 over the lower packer assembly 2, preferably in the pattern depicted in Figure 8 and preferably using the collar device 34 shown on Figure 10 to fasten the strip material to tool 22. At this point, the movable crosshead 14 is in the fully raised position with collet 28 closed. Collet 24 is then closed and collet 28 is opened. Power head 16 then moves tool 22 downward while wrapping strip material 21 thereabout. Movement of the tool downward and the rate of rotation of the material payoff assembly 27 are fixed and coordinated by the pitch of lead screw 23. When the movable crosshead 14 reaches the lower end of its travel, collet 28 is closed, upper collet 24 is opened and brake 19 is set so that the wrapped-on strip material 21 will not become unwrapped during the elevation of crosshead 14. Crosshead 14 is then elevated by reversing power head 16, while no power is transmitted to material payoff means 27 due to the fact that the drive thereto is ratcheted. The process of alternately raising and lowering crosshead 14 to feed and wrap portions of tool 22 is continued until the upper packer assembly 5 is reached and wrapped. A collar similar to that shown in Figure 10 is then wrapped about the upper packer assembly 5 to lock the wrapped strip thereto. The strip material is then cut off and the tool 22 is ready for use. Since there is no longer any need
for the machine to remain at the wellhead, and in fact, it can be transported to the next job, tool 22 can be lowered completely through the wrapping area, fitted with a split collar as a stop on the wellhead to permit removal of the machine, and the process of patching the well can proceed.

Before proceeding with a discussion of the well patching procedure, the construction of the upper and lower packer assemblies will be described with reference to Figures 4 and 5 (Lower) and Figures 6 and 7 (Upper) packer assemblies, respectively. These Figures illustrate that the essential features of the respective packer assemblies are: 1) Expandable means (the packers) at the upper and lower ends of the tool permitting expansion from the tool diameter to fit forcibly against the well casing, 2) Spindle means preferably located adjacent the lower packer assembly which on command can permit rotation of the mandrel and upper packer assembly with respect to the lower packer assembly, and 3) Valve means permitting controlled circulation of fluid under pressure along the inside face of the newly formed well liner.

Figures 4 and 5 illustrate the upper and lower portions of the lower packer assembly, with reference character 64 representing the steel body of the assembly, 51 representing the packer itself, and being an inflatable rubber sleeve fastened at the ends to the assembly body 64, reference character 50 representing the spindle held together from rotation by shear pin 53, rollers 54 which rotate in race 65 after the shear pin is broken and the upper portion of the
tool is rotated from the surface, valves 10 are circulating valves operated by interior tool hydraulic pressure in the hollow core 6, holes 71 communicate between the tool core 6 to the inner face of the packer 51 to inflate packer 51 in response to hydraulic pressure P1 in core 6, check valve 58 of the ball-check type admits fluid contents of the well to the interior of the tool as the tool is lowered into the well so that interior pressure in the tool is equalized to the exterior pressure, screen 72 prevents entry of well solids into the interior of the tool, and 55 represents pressure discs to be blown after the well patch is completed and the upper and lower packers are to be deflated for withdrawal of the tool from the well. It will be appreciated that additional ball-check valves may be employed in patching wells which have excessive amounts of suspended solid material and that the area of the screen can be varied depending upon the conditions encountered in the well.

In Figures 6 and 7 reference character 60 represents the upper packer, which is fastened at the ends to the steel body of the upper packer assembly, 61 are rupture discs which rupture at pressure P2 to inflate the upper packer (pressure P2 being higher than pressure P1, the pressure at which the lower packer is inflated), valves 62 are check valves that equalize the head pressure in the well with the pressure on each side of rupture discs 61 to prevent premature bursting of said discs 61, passages 63 lead to the interior face of
packer 60 to inflate it. Both packers are shown in the
deflated and in the inflated condition on opposite sides of
the tool.

The tool is intended to be operable to patch holes in
well casing or tubing without removing the liquid contents of
the well. This is not only for convenience in the field but
also due to the fact that disposal of the well contents could
pose an environmental problem.

With the tool prepared as described in accordance with
Figure 1 hereinbefore, it is lowered into the well from
tubing string 3 to the location of the leaking area in the
well which must be patched. It is to be emphasized that the
patch can be of considerable length, e.g., 30 feet, 50 feet
or even 100 feet or more. As the tool descends, ball-check
valve 58 opens to equalize interior pressure in the hollow
core of the tool 6 with the pressure in the well. The
hydraulic signals transmitted to the tool from the surface
depend upon the differential in pressure within the tool, not
the absolute pressure. When the tool has reached the area to
be patched, as indicated in Figure 2, pressure in the
interior of the tool is increased to P1 and the lower packer
is inflated against the casing 32 of the well. This act
locks the lower packer assembly against the casing so as to
prevent movement and breaks the collar 34, pushing the collar
34 and the first wraps of the lining strip 21 firmly against
the inner face of the well casing 32. The tubing string is
then rotated from the surface in the direction opposite the
wrapping direction of the liner strip to break the shear pin 53. The upper portions of the tool are then rotated to unwrap the liner strip 21 against the inner face of the casing 32 all the way to the upper packer so as to arrive at the position shown in Figure 3. The resilient nature of the strip material causes it to move against the casing as the strip is unwrapped in a manner akin to the uncoiling of a coiled spring. Internal pressure in the tool is then increased to pressure P2 to rupture the discs 61 and inflate the upper packer. The inflated upper packer 60 breaks the join of the upper collar 34 and presses it firmly against the casing along with the upper wraps of the liner strip 21. Internal pressure is then raised to P3 to open circulating valves 10 and hot water is circulated along the inner face of the liner to set the heat settable resin positioned between the overlapping metal strips 21. When sufficient time at temperature to set the resin has passed, the internal pressure is raised to P4 to blow rupture discs 55. This equalizes the internal and external pressures and deflects the packers, whereupon the tool may be removed from the repaired well. Bypass passages 67 permit the circulating liquid to move past the upper packer without deflecting it. Alternatively, longitudinal grooves may be provided in the periphery of the upper packer.

Figure 8 depicts a preferred pattern for starting the wraps of liner strip about the tool. Collar 34 is provided with a longitudinal set of slots 35 into which the ends of metal strip 21 may be inserted. Between metal strips 21,
strips of plastic screen, such as fly screen, impregnated with liquid epoxy are placed (reference character 36) until four strips of each description have been located. Conveniently, the end of each strip is cut at an angle as shown in the drawing. The flap 37, shown more advantageously in Figures 9 and 10 overlaps the located ends of the liner strips 21 and 36 to provide a more secure anchor for the strip, and prevent it from becoming unraveled from the tool. The screen material can be fastened to collar 34 using a hot glue gun. It is very important that the strip be securely fastened to the tool and remain so during descent of the tool into the well, becoming detached from the tool only upon commands from the surface.

Figure 9 depicts the pattern of the thin strong sheet material from which the collar is made. The pattern is rectangular and bears an aligned row of slots 38 punched adjacent an edge thereof. A corresponding set of ears 39 parallel to slots 38 is placed at a distance corresponding to the diameter of the collar 34 made when the pattern 40 is rolled into a cylinder. Slots 35, also shown in Figure 8, are punched adjacent the opposite edge of the pattern 40 to hold the lining strip. It will be seen that a flap 37 is formed when pattern 40 is rolled into a cylinder. Ears 39 may be fastened to pattern 40 in breakaway fashion as by spot welding, or may be die-formed into the pattern. The ear-and-slot system holds together firmly during wrapping of the lining strip and descent of the wrapped tool into the well.
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The force of the expanded packers exerted internally upon the collar easily ruptures the collar joins when the proper command is given from the surface and the collar material, being springy, presses firmly against the well casing. The collar material can be 0.010 inch thick, aged beryllium copper sheet or strip of high strength.

Figure 10 depicts the pattern 40 of Figure 8 after it has been rolled into the collar. Slots 38, ears 39, flap 37 and strip-holding slots 35 are shown. Dimples 43 keep collar 34 from slipping on the packer during the wrapping process. A supplemental set of slots 42 and catches 43 cut into pattern 40 may be provided to hold tab 37 tightly to collar 34 as shown in Figure 11 to facilitate passages of the collar-wrapped packer through machine 11. Catches 43 are released from the lower collar to permit attachment of the liner strip material to tab 37.

Figures 12A through 12E depict an additional safety feature to prevent loss of the tool down the hole during the wrapping process. Each mandrel section can be provided with an annular recess 4a near the top end thereof. A shoulder 92 surrounds the tool at a location above upper collet 28. Shoulder 92 is activated by valve 93 and prevents mandrel section from moving down even if upper collet 28 is open, as shown in Figure 12B. Shoulder 92 is driven by shaft 94 and spring 95.
It is to be appreciated that the well liner provided in accordance with the invention must pass a "gage" test and a pressure test after it is formed to demonstrate that it presents no impediment to passage of well tools and that it will prevent seepage of undesirable materials from the interior of the well into the environment. This represents a stringent set of criteria which must be passed. Use of 0.010 inch thick strip of beryllium copper alloy; with interspersed epoxy provides in four layers essentially the strength of the original steel casing material and provides far greater corrosion resistance especially to chlorides.

The present invention is directed to various improvements in the process and apparatus for preparing and installing new linings in bores such as oil well casings which have developed cracks or holes from corrosion and are thereby considered threats to the environment, together with other unwanted effects. As another example, a perforated area initially designed to access a hydrocarbon reservoir can be patched to allow exploitation of another hydrocarbon producing zone.

In my co-pending United States patent application Serial No. 223,557, the text of which is set forth hereinbefore, I have described apparatus and method for wrapping a resilient strip material about a mandrel with the wrapped strip being held firmly against the mandrel at the ends thereof as by collar means which prevent unwrapping the wrap, inserting the mandrel into a bore to be lined and creating a lining at a
selected place within the bore by unwrapping the strip material from the mandrel to create a lining consisting of spirally placed strip, e.g., metal strip interleaved with layers of a curable liquid resin which is held in place against the bore by resilience of the strip and bonded together by effecting curing of the resin. A downhole tool for effecting the lining, a machine for wrapping the tool and a process for creating the new lining were disclosed. An extensive testing program has led to a number of improvements in the apparatus and process which have led to an improved leak resistance upon pressure testing of the linings produced. The following pages are directed to a description of the said improvements.
In accordance with the present invention, an improved mandrel upon which the resilient lining strip is wrapped in overlapping spiral fashion is made of lockable inner and outer parts which, once the lock is released, telescope with respect to each other under the force of gravity, with the outer portion of the mandrel upon which the lining material is wrapped rotating with respect to the core portion, causing release of the resilient lining strip from the mandrel against the wall of the bore in which the mandrel is placed. Further improvements include preparing the mandrel from telescopicable segments actuable sequentially from bottom to top so as to release the wrapped strip in spiral fashion against the bore wall from bottom to top of the patch area in the bore. The downhole tool itself is fitted not only with upper and lower packers but also with a supplemental packer below the lower packer, the function of which is to anchor the lower end of the tool to the bore wall. Once the spiral wrapped strip has been released against the bore wall, both upper and lower packers are inflated to release the collar means and to drive the upper and lower ends of the strip against the bore wall. This feature assists in controlling circulation of fluids in the bore in the region of the tool. In wrapping the strip in spiral fashion about the mandrel of downhole tool, liquid curable resin is spread directly against the strip surface. The improved mandrel of the invention permits suspension thereof in a bore to be lined on a wire jointed straight tubing, or coiled tubing. Since rotation of the
mandrel in the bore to effect unwrapping of the wrapped liner material therefrom is controlled by means within the mandrel utilizing the force of gravity, turning of the mandrel from the surface is rendered unnecessary.

The wrapping machine itself has also been improved to provide ready adaptation to the lining of bores of varying diameters.
The testing program mentioned thereinbefore involved a consideration of the geometry of the patch created by the wrapped lining material which is initially wrapped in overlapping layers about the mandrel. This wrapping is transferred from the mandrel outside diameter (OD) to the bore wall inside diameter (ID) to be repaired. The inner diameter of the bore to be repaired must, perforce, be larger than the diameter of the mandrel bearing the wrapped lining material since the mandrel fits within the bore. This means that if the liner is transferred laterally from the mandrel to the bore, the edge-to-edge spacing of adjacent turns of the strip material wrapping will have to increase due to the increase in diameter of the wrapping. In order to maintain the same edge-to-edge spacing between adjacent turns of the wrapped liner strip, the overall length or height of the liner material wrapping must be decreased as the unwrapping of the liner from the mandrel to the bore wall proceeds. Stated in another way, the pitch of the spiral created in the spirally-wrapped liner material by the wrapping operation must decrease when the liner material is transferred from the mandrel on which it is wrapped to the bore surface to be repaired if this edge-to-edge spacing of the strip is to be maintained during the transfer. It can be seen that the area of material wrapped on the mandrel is finite. It has been found that the strip material area applied to the bore wall should be the same as it was on the mandrel surface. The diameter of the patch is greater than the diameter of the
mandrel, hence the cylindrical height of the patch must be less than the cylindrical height of the strip material spirally-wrapped on the mandrel.

The means invented to accomplish the special purpose of the invention will be described under the following headings:
As shown in Figures 13 and 14, the mandrel 100 comprises inner hollow section 101 bearing lead screw 102 and upper push-rod 103 fixed to inner hollow section 101, and outer tube 108 which is telescopable and rotatable with respect to hollow section 101. Moveable push-rod 104 fits within hollow section 101 and has an enlarged end section 105 which closely fits the inner wall of hollow section 101 so as to hold balls 106 therebetween. Balls 106 may fit in detents 107 in the inner wall of outer tube 108 when the mandrel is in locked position. As long as the enlarged end of lower push-rod 104 bears against balls 106 in the position shown in Figure 1, outer tube 108 is locked to hollow section 101. When push-rod 104 is raised as in Figure 14, a reduced section 101A thereof is brought opposite balls 106 and outer tube 108 becomes unlocked from inner hollow section 101 by release of balls 106 from the locked position. Roller pin 109 inserted into the inner wall of outer tube 108 engages lead screw 102 causing rotation of outer tube 108 with respect to inner section 101 as the outer tube 108 descends with respect to inner section 101. The mandrel may be fitted with male 110 and female 111 threaded connectors to join mandrel sections into a given downhole tool. It will be appreciated that generally the downhole tool will be anchored to the bore wall at the bottom end by a supplemental or anchoring packer devoted to that purpose and inflatable by hydraulic pressure applied through the hollow center of the mandrel. Accordingly, once balls 106 are released by action of the lower
moveable push-rod 104, the mandrel will be free to descend under the action of gravity. The collapsing action of the outer tube 108 with respect to the lead screw tube 101 will shorten the mandrel as shown by the length "A" on Figure 1 and the length "B" shown on Figure 14. Shortening the mandrel to the length "B" shown on Figure 14 exposes a portion of upper push-rod 103 above the upper end of mandrel 100. This actuates the push-rod in the adjoining upper mandrel section and permits release of wrapped liner material therefrom. It will be noted that the lower end of outer tube 108 terminates at 112. Since the entire length of mandrel 100 is to be wrapped with liner strip, a collapsing section of mandrel 100 is provided as indicated at zone "C" thereon upon which liner strip may be wrapped. The collapsing section may comprise a series of washers 113 which may be kept separate by springs 114. Such a structure permits wrapping strip about the mandrel but still permits the requisite unwrapping action caused by relative motion of the mandrel parts and concomitant rotation of outer tube 108.

It is to be appreciated that the completed downhole tool, securely locked to prevent rotation and unwrapping of the strip liner material, with upper and lower packers at the termini of the wrapped strip area, with cuffs or collars securely holding the upper and lower ends of the wrapped strip, with a supplemental packer at the lower end to provide an anchor to the bore and a centralizer if needed is lowered down the bore from a suspending means. The defects to be patched may be many hundreds or even thousands of feet down.
the bore. The lower packer 29 and supplemental packer 138 are rigidly attached.

Once the tool has been located at the position of the bore to be patched, the supplemental packer is inflated to anchor the tool in the bore. Preferably, hydraulic pressure transmitted from a pump on the surface through the hollow suspending means and the hollow tool is used to inflate the packer. The push-rod of the bottom mandrel section is then actuated by a piston located below the mandrel section and actuated by hydraulic pressure after the bottom packer is anchored. Rotation of the bottom mandrel portion then proceeds as the locking mechanism is released. The strip unwrapping then proceeds sequentially up the tool, which is lowered slowly against the anchored supplemental packer until all the wrapped strip material is released against the bore wall. Both upper and lower packers are inflated against the bore wall to force the retaining cuffs thereagainst. The packers are then deflated. The resin between layers of strip is then cured, as by hot water forced down the hollow center of the tool and circulated along the patch.
THE PROCESS

The process of the invention comprises preparing the mandrel described hereinbefore by assembling end-to-end a series of mandrel segments which are individually collapsible in the controlled fashion described. Liner strip made of resilient material, which may be, for example, glass fiber or carbon fiber reinforced plastic material, corrosion-resistant metal material such as beryllium copper, etc. is wrapped in spiral fashion about the mandrel with a layer of a curable resin being deposited on the strip surface between overlapping layers of the wrap. The ends of the wrap are then securely fastened to the mandrel surface by means such as metallic cuffs or collars which lock together. The length of the wrapped strip is substantially the length of the patch to be made in the bore to be repaired. The length of each mandrel segment is that which can conveniently be handled in the field, e.g., about thirty feet. The wrapped downhole tool is then lowered down the hole to be repaired to the point or areas of the leak to be patched and is locked against the bore wall by inflation of a packer at the lower end of the tool. For this purpose, it is convenient to use a coiled tubing unit such as that commonly used in oil field practice for the purpose of suspending the tool down the hole. Hydraulic commands can be transmitted down the tubing and used to control the desired functions of the tool in the hole. Pressurization to inflate the lower-end packer can also be used to actuate the inner push-rod in the lowermost mandrel segment to initiate unwrapping of the liner strip.
therefrom. This may be accomplished by actuation of a piston 113 at the bottom of the lowermost mandrel segment as shown in Figure 15 of the drawing. Piston 113 operates within cylinder 114 located below the lowermost mandrel segment and actuates the lower push-rod 104 of the said mandrel segment. Piston 113 operates by differential hydraulic pressures shown by the large piston diameter 116 as against the small push-rod diameter 117. A vent 115 may be provided in the cylinder wall to prevent hydraulic locking of piston 113. Once the lower mandrel segment is unlocked, unwrapping of the strip proceeds by rotation of the outer tube section 108 with respect to the inner lead screw tube 101 and unwrapping of the wrapped strip proceeds sequentially upwards as the mandrel segments are actuated sequentially from bottom to top. Once unwrapping is complete, both the upper and lower packers, which are located beneath the cuffs holding the wrapping strip, are actuated hydraulically and the cuffs are forced against the bore wall, where they remain by spring action of the cuff material, which is preferably made of spring temper metal. The upper and lower packers may then be deflated and the liquid resin between the layers of liner strip is cured. If the resin employed is a thermosetting resin, hot water may be circulated through the tool to the inside surface of the patch. Once a cure has been effected, the locking packer is deflated and the tool is removed from the hole. The resin employed may be of any type which may be cured in the hole.
THE SURFACE TOOL OR MATERIAL APPLICATION DEVICE

Figure 16 depicts in plan view an improved machine for spiral wrapping liner strip about the mandrel of the invention. The machine is adapted to fit atop a wellhead 132 so that, as wrapping of the mandrel 100 proceeds, the wrapped mandrel may be lowered down the hole. The machine comprises a frame having a moveable crosshead 134 bearing lower collet 24. A fixed crosshead 148 bears a power head 135 containing the lead screw drive mechanism which controls the rate at which the crosshead 134 moves up and down the lead screws 136. The lead screw drive mechanism also coordinates the rotation of the winding mechanism 137 to the downward travel of the mandrel section being wound to produce the proper wrap of strip 21 about the mandrel. Collets 24 and 28 mounted on the moveable crosshead and the frame, respectively, serve to prevent the tool from dropping down the well. Collet 24 is open while the crosshead 134 is raised and is closed to grip the mandrel when crosshead 134 descends. Collet 28 is closed while the crosshead 134 rises and open when crosshead 134 descends. The collets are of the type which is normally closed and are opened by application of hydraulic pressure. Winding mechanism 137 supports spindles 15 which hold the coils of liner strip 21 on spools 30. A centralizer 18 and the bottom or anchoring packer 138 are shown in broken line at the bottom of mandrel 100. Lower packer 29 is also indicated.
Resin applicator assembly 139 feeds liquid resin directly to a face of the uncoiling strip 21 and is explained in more detail in relation to Figure 17.

Advantageously, the machine is designed to run several casing patch sizes (4-1/2", 5-1/2", 7-5/8", for example) using the same basic machine. For this purpose lead screw mechanism 135 is provided with change gears, spindles 15 are provided with a mechanism to make the proper angle in relation to the mandrel section being run. The change gears incorporated in the lead screw drive mechanism provide the correct relationship between rotation of winding mechanism 137 and downward travel of mandrel segment 100 with moveable crosshead 134 so that the proper wrap will result. The change gears can be shifted as indicated by gear shift 140 to provide the correct ratio. The spindle angle can be controlled by a cam adjuster with a lobe setting for each size. The collet jaws 24 and 28 must be changed out for the mandrel size being run.

It is to be appreciated that the mandrel is prevented from turning during the wrapping operation and that all mandrel segments are wrapped while in the locked position. The winding mechanism 137 is provided with a brake 141 which prevents reversal of winding mechanism 137 when moveable crosshead 134 is being raised.
Figure 17 shows in more detail the mechanism for applying liquid resin to the surface of strip 21. Winding mechanism 137 rotates counter clockwise looking down and includes spindles 15 on which spools 30 are mounted. Liquid resin is fed from pressurized canister 142 to metering pumps 143 of the positive displacement type thence to resin applicator head 144 which is mounted on pivoting arms 145. Arms 145 are attached to spindles 15. Arrows 146 indicate the path of the liquid resin. Pumps 143 are geared to fixed gear 147 and thus supply resin only when winding mechanism 137 is rotating. The resin applicator head 144 consists of a hollow container having a narrow slit, e.g., 0.125 inch, facing the strip surface on which the applicator is in riding contact with the slit extending completely across the width of the strip being coated. A resin applicator is supplied for each of strips 21 being wound.

It is found in practice that application of liquid thermosetting resin, e.g., a liquid epoxy, works very well and that the resin acts as a lubricant. Of course, other adhesives and resins which may be thermosetting, time-setting, etc. as those skilled in the art will readily understand, may be employed. The adhesive coating between the liner strip and the bore being lined insulates against electrolysis.

The improved mandrel design and machine provide capability of using a wire line or coiled tubing unit (standard oil field procedures) for the purpose of lowering the wrapped
mandrel down a hole or bore, e.g., an oil well. This benefit resulted from elimination of the need for mechanical rotation from the surface. In the case of the wire line, self-contained pressure vessels can be incorporated in the tool and actuated from the surface by electrical or other means supplied from an appropriate location. Heating elements can be built into the tool and utilized to cure adhesives.
WHAT IS CLAIMED IS:

1. A method for relining bores comprising:

   spiral wrapping a plurality of layers of resilient strip form lining material about a hollow mandrel and mechanically securing said material to said mandrel at the ends of said spiral wrapping;

   inserting said mandrel and lining material into a bore to be relined;

   unwrapping said material from said mandrel so that said material expands until in contact with the bore creating a lining for said bore; and

   removing said mandrel.

2. The method of claim 1 wherein said material is wrapped about said mandrel with said layers overlapping each other.

3. The method of claim 1 wherein said strip form lining material is metallic material having a yield strength of at least 50,000 psi.

4. The method of Claim 3 wherein said layers of metallic strip material are interleaved with a layer of strip material bearing a heat settable liquid resin.

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5. The method of claim 1 wherein said mandrel comprises upper and lower packer assemblies separated by a length of mandrel material corresponding to the desired re-lining length, said wrapping of strip material is fastened mechanically at the ends thereof to said packer assemblies, said strip material is unfastened from said lower packer assembly by inflating said assembly against the bore wall, said strip material is unwrapped from said mandrel by rotating said mandrel from a point adjacent said inflated lower packer assembly in a direction opposite to the wrapping direction of said strip material and, when said unwrapping has proceeded to said upper packer assembly, inflating said upper packer assembly to detach the upper mechanical fastening there-from.

6. The method in accordance with claim 5 wherein said strip material is beryllium copper interleaved with screen material impregnated with a heat settable epoxy resin and said resin is set by means of hot water.

7. The method of claim 1 further comprising the step of including a plurality of layers of material impregnated with a heat settable resin between said layers of strip form lining material and heat setting said resin before removing said mandrel.
8. The method of claim 3 wherein the step of heat setting said resin to bond said lining material together is accomplished by:

circulating hot water from said mandrel along the inner face of said lining in said bore.

9. The method of claim 4 wherein collar means are employed to fasten the ends of said wrapping of strip material to said packer assemblies.

10. A mandrel for repairing a bore comprising:

a lower packer assembly having a diameter less than said bore capable of expanding in size to the diameter of said bore;

a mandrel connected to one end of said lower packer assembly having a diameter of less than the diameter of said bore;

an upper packer assembly having a diameter less than the diameter of said bore, said upper packer assembly being expandable to a diameter equal to the diameter of said bore; and

means for expanding said lower packer assembly prior to the time when said upper packer assembly is expanded.
11. The mandrel of claim 10 further comprising a locking assembly located between said lower packer assembly and said mandrel such that when unlocked, said locking assembly permits said mandrel and upper packer assembly to rotate independent of said lower packer assembly.

12. The mandrel of claim 10 wherein said upper and lower packer assemblies expand by the application of pressure created by pumping a fluid into said mandrel.

13. The mandrel of claim 12 further comprising a circulating valve located between said upper and lower packer assemblies, which when activated, permits said fluid or gas to pass from said mandrel into said bore.

14. The mandrel of claim 9 wherein said circulating valve is activated only when both of said packer assemblies are inflated.

15. The mandrel of claim 10 further comprising a centralizer.

16. The mandrel of claim 12 wherein the inflation of said upper packer assembly is regulated by one or more rupture discs.
17. The mandrel of claim 12 wherein said mandrel further comprises a pressure release mechanism located below said lower packer assembly which when opened depressurizes said mandrel.

18. The mandrel of claim 17 wherein said pressure release mechanism comprises at least one rupture disc.

19. A machine for preparing a tool designed to repair leaking sections of well casing which comprises:

1) a rectangular frame having upper and lower openings at substantially the center line;
2) a fixed crosshead in said frame;
3) a movable crosshead bearing collet means;
4) said fixed crosshead bearing rotatable material payoff means, drive means therefor and brake means permitting rotation of said material payoff means in a single direction only;
5) means for elevating and lowering said movable crosshead;
6) collet means fixed about the said upper opening on said frame;
7) means for feeding mandrel material through said collet means, said drive means and said material payoff means and through the lower opening in said frame; and
8) means for holding strip material on said material payoff means whereby mandrel material may be wrapped portion by portion with said strip material to a desired length to form a tool for repairing oil well casings.

20. A machine in accordance with claim 19 wherein said collets are normally in a closed position and are opened hydraulically.

21. A machine in accordance with claim 20 wherein at least one of said collets is in closed position during operation.

22. A machine in accordance with claim 19 wherein said means for elevating and lowering said movable crosshead comprises a hollow lead screw operated by said drive means.

23. A machine in accordance with claim 22 wherein said brake means is set to prevent rotation of said material payoff means when said drive means is employed to elevate said movable crosshead.

24. A machine in accordance with claim 19 wherein said means for elevating and lowering said movable crosshead is a hollow lead screw and said rotatable material payoff means is a tube surrounding said lead screw.
25. A machine in accordance with claim 24 wherein said lead screw and said rotatable material payoff means are operated by a common reversible power head which is ratcheted with respect to said rotatable material payoff means such that said rotatable material payoff means rotates only when said lead screw is descending.

26. A machine in accordance with claim 19 wherein said collet means fixed to said movable crosshead is open when said movable crosshead is rising and closed when said movable crosshead is descending.

27. A machine in accordance with claim 19 wherein said rotatable material payoff means is provided with a plurality of axles angularly spaced about said material payoff means and located at an angle with respect to the centerline of said material payoff means, said axles being adapted to hold reels of strip material.

28. The method for preparing a downhole tool for inserting a new bore of substantial length in a leaky well casing which comprises the steps of:

1) connecting a lower packer assembly to a hollow drill steel mandrel;
2) positioning said mandrel above a well to be repaired;
3) spirally wrapping a plurality of overlapping layers of metallic strip material interspersed with layers
of screen material impregnated with heat settable liquid resin about said packer assembly and a portion of said connected mandrel;

4) lowering said wrapped portion into said well;

5) wrapping additional portions of drill steel mandrel and lowering said wrapped portions into said well until a downhole tool of desired length is prepared; and

6) locating an upper packer assembly at the upper end of said tool and fastening said strip material thereto whereupon a tool is prepared which may be lowered into said well to provide a new bore of substantial length in a leaky portion thereof.

29. A collar for fastening the ends of a plurality of overlapping metal strips to a cylindrical object to permit spiral wrapping of said strip there around which comprises a rectangular metal sheet provided with a series of aligned slots punched adjacent an edge thereof and a series of aligned breakaway metal tabs parallel to said slots and spaced therefrom by about the circumferential distance of said cylindrical object to be wrapped such that said tabs are engageable in said slots when said sheet is wrapped as a collar about said cylindrical object with said aligned tabs being spaced from the edge of said sheet opposite said aligned slots such that said sheet when formed into a collar will provide a metal flap into which the ends of said strip to be spirally-wrapped wrapped may be inserted.
30. A collar in accordance with claim 29 wherein said flap is provided with aligned slots into which a corner of each of the metal strips to be wrapped may be inserted with said flap being above said metal strips.

31. A collar in accordance with claim 26 wherein said flap is provided with an array of dimples to assist in gripping said strip to be spirally-wrapped.

32. A mandrel assembly for inserting a spirally-wrapped strip material liner into a bore to be repaired; comprising means contained within said mandrel assembly for unwrapping strip material liner from said mandrel assembly, lockable means located within said mandrel assembly capable, when unlocked, of controlled telescoping of said mandrel assembly such that said spirally-wrapped strip material when unwrapped against said bore will possess substantially the same edge-to-edge spacing as it possesses when wrapped on said mandrel, and a supplemental packer means at the upper and lower ends of said assembly defining the length of said assembly to be wrapped with said strip material liner, a supplemental packer assembly located below said defined length adapted to engage the bore to be lined when said supplemental packer assembly is inflated.

33. A mandrel assembly in accordance with claim 32 comprising concentrically mounted push-rod means, hollow tubular lead screw means surrounding said push-rod means
and outer tubular means engaging said lead screw, 
locking means capable in the locked position of pre-
venting relative movement of said outer tubular means 
and said hollow lead screw, and in the unlocked position 
permitting relative linear movement therebetween, said 
linear movement of said outer tubular means causing 
rotation thereof with respect to said lead screw.

34. A mandrel comprising a plurality of the mandrel assem-
blies as defined in claim 1 connected together to be 
operated sequentially.

35. A mandrel assembly in accordance with claim 33 wherein 
said push-rod means include a push-rod segment moveable 
within said hollow lead screw and a push-rod segment 
affixed to the upper end of said hollow lead screw.

36. A telescoping mandrel assembly in accordance with claim 
32 wherein the telescoping distance for said mandrel 
assembly is defined by the length of said outer tubular 
means and the portion of the length of said mandrel 
surface representing said telescoping distance is filled 
with collapsible means.

37. The mandrel assembly of claim 36 wherein said collap-
sible means comprises washers having the mandrel 
diameter separated by spring means.
38. A mandrel assembly in accordance with claim 33 wherein said push-rod means are hollow, and said supplemental packer means are inflated by hydraulic pressure transmitted therethrough.

39. A mandrel in accordance with claim 38 adapted to be suspended downhole from a cable or coiled tubing.

40. The method for lining a bore wherein a plurality of layers of strip form material is spirally-wound upon a mandrel and affixed thereto at the ends of the spirally-wound wrapping, the wrapped mandrel is lowered into a bore to be repaired, the bottom end of said wrapped mandrel is anchored against the walls of said bore, said spirally-wound strip material is unwound from the bottom to the top of said wrapping against the wall of said bore by rotation of said mandrel while maintaining the spacing of said spirally-wound strip form material essentially the same against the wall of said bore as it was on said mandrel, by telescoping the length of said mandrel as said unwrapping proceeds, said telescoping being coordinated to rotation of said mandrel surface.

41. The method in accordance with claim 40 wherein said spirally-wrapped strip form material is secured to said mandrel at the ends of said wrapping by mechanical means and said mechanical means are released at substantially the same time after said wrapping is unwound from said mandrel.
42. The method in accordance with claim 40 wherein said mandrel is hollow; said anchoring means and said mechanical fastening means are operated by hydraulic, mechanical, or electrical means.

43. The method in accordance with claim 42 wherein said anchoring means and said mechanical fastening means are operated from the surface by hydraulic pressure.

44. The method in accordance with claim 40 wherein said layers of strip form material are interleaved with layers of a curable resin and said resin is cured after said wrapping is unwrapped against the bore wall to seal between said layers.

45. The method in accordance with claim 40 wherein said mandrel is comprised of a plurality of mandrel segments each of which is capable of effecting mandrel surface rotation and telescoping under the force of gravity when the lower end of said mandrel segment is in fixed position, said telescoping being effected by lowering of said mandrel while the lower end of said mandrel is anchored to the wall of said bore, with sequencing means which activate each mandrel segment sequentially from the lower end of said mandrel as unwrapping of said strip form material proceeds upwardly along said mandrel.
46. The method in accordance with claim 40 wherein said resin is a thermosetting liquid resin which is cured by hot water circulated down said hollow mandrel and upwards along the inner face of the lining created in said bore by said unwrapped strip form lining material.
### INTERNATIONAL SEARCH REPORT

#### I. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both National Classification and IPC:
- IPC(4) E21B 33/10
- U.S. Cl. 166/277, 191:493/300

#### II. FIELDS SEARCHED

Minimum Documentation Searched:

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<th>Classification System</th>
<th>Classification Symbols</th>
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<td>U.S.</td>
<td>166/277, 380, 387, 187, 191, 242, 63</td>
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<td>493/300 ,138/150, 154</td>
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Documentation Searched other than Minimum Documentation to the extent that such documents are included in the fields searched:

#### III. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of Document, 11 with indication, where appropriate, of the relevant passages 12</th>
<th>Relevant to Claim No. 13</th>
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<tbody>
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<td>X</td>
<td>U.S., A, 4,566,535 (Sanford) 28 January, 1986 See Fig. 2</td>
<td>10,12-14,17 15,16 and 18</td>
</tr>
<tr>
<td>Y</td>
<td>U.S., A, 4,246,964 (Brandell) 27 January, 1981 See Fig. 5</td>
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</tr>
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<td>U.S., A, 3,364,993 (Skipper) 23 January, 1968</td>
<td>1-18</td>
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<tr>
<td>A</td>
<td>U.S., A, 4,261,785 (HUNTER) 14 APRIL, 1981</td>
<td>19-28</td>
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</table>

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  - "A" document defining the general state of the art which is not considered to be of particular relevance
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

#### IV. CERTIFICATION

Date of the Actual Completion of the International Search: 29 March, 1989

Date of Mailing of this International Search Report: 1 MAY 1989

International Searching Authority: ISA/US

Signature of Authorized Officer: [Signature]

William P. Neuder