FIG. 4

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The method of manufacturing crepe paper according to the present invention comprises causing a web of paper to adhere to a first conveyor means with a first peripheral speed and transferring the web of paper by longitudinal movement to a second conveyor means moving with a peripheral speed less than first peripheral speed, and causing the web to be freed from adherence to the first conveyor means. The web passes between and in contact with both said conveyor means, after which it is freed from contact with at least the first conveyor means. The web is compressed immediately after creping while held in the shortened or creped condition so as to press the crepe in place and to prevent the crepe from "pulling out".

More specifically, the web of paper is passed through a nip formed between two rolls rotating in mutually opposite directions and with different peripheral speeds. The web of paper is made to adhere to the roll having the faster peripheral speed before entering the nip, is creped, pressed between the rolls, and then is freed from adherence to the faster roll, after passage through the nip. The web may adhere to the slower moving roll after passage through the nip, but this is not essential; all that is necessary is that the web should not adhere to the faster moving roll after passing through the nip.

Apparatus according to the invention for carrying out the above process comprises a first roll, a second roll forming a nip with the first roll through which nip a web of paper is adapted to be passed and compressed during such passage, and a drive mechanism adapted to rotate said rolls in mutually opposite directions at speeds such that the peripheral speed of the second roll is less than that of the first roll.

From the above, it will be seen that the web of paper is pressed while it is held by pressure of the nip in its shortened or creped condition. The method according to the invention, therefore, eliminates a disadvantage of present creping methods in which the pressing is done at an appreciable time after, and at a distance from, the creping operation such that the web has been removed from the roll and much of the original crepe is lost. In addition, the method according to the invention imparts desirable properties to the finished product. Whereas in existing creping methods, the sheet buckles and folds as material accumulates in front of the doctor, in the method according to the invention the sheet need only compress and wrinkle sufficiently to match the speed of the second roll. Hence, by adjusting the differential speed to a proper value, the crepe can be made much finer and more uniform. Different creping may be obtained by varying the differential speed. Also, whereas when a conventionally creped sheet is pressed in a conventional roll nip the small wrinkles are flattened, lengthening the web, according to the present invention the web is held in compression as the nip pressure increases to its maximum value. This not only presses the small wrinkles in place and bonds them together but causes a certain amount of the elastic deformation which takes place ahead of the roll nip to become a permanent deformation. The imparted crepe is less likely to be lost in subsequent operations on the web. In fact, by proper adjustment of such variables as the nip pressure and differential speed, etc., it is possible to impart desirable properties, such as stretchability to the finished product without actually visibly creping the web. The pressing action also leads to a flat, smoother sheet enabling more efficient heat transfer when the sheet comes into contact with the drying cylinders.

The final product will be superior in many ways to conventional creped paper. The paper, while highly stretchable, will exhibit less visible crepe and the force required for extension will be greater than that for ordinary creped paper. In addition, it will be possible to obtain a smoother, better printing surface at least on one
The invention will now be described with reference to the accompanying drawings, in which: FIGURE 1 shows a plan view of apparatus capable of carrying out the process according to the invention. FIGURE 2 shows an elevation view of the apparatus illustrated in FIGURE 1, with the driving mechanism for the rolls omitted, FIGURE 3 is an expanded view, in section, of the paper web passing between two of the rollers shown in FIGURES 1 and 2, and FIGURE 4 is a graph showing compressive force, elastic compression and total compression in the paper web as a function of distance as the web passes through the regions shown in FIGURE 3.

As shown in FIGURES 1 and 2, the web 19 to be treated should be in a partly wet state and is first pressed against the first creping roll 12 by an auxiliary transfer roll 11. The nature of the surfaces of these two rolls should be such that the web 19 will adhere firmly to the first roll 12 after being pressed on by the transfer roll 11. The first roll 12 in operation forces the web adhering to its surface into the nip formed between this first roll 12 and a second creping roll 13. Both of these creping rolls 12 and 13 are connected to a driving mechanism, which in this example consists of couplings 15, gear reducers 16, variable gear drive 17 and belt drive 18 (as shown in FIGURE 1), in such a way that the second roll 13 is run at a lower peripheral or surface speed than the first creping roll 12. The difference in peripheral speed of the two rolls should not be too great, so that the paper will not "crowd together" too much thereby causing irregular creping. The friction of the web against the second slow-moving roll causes it to be compressed in region 20 just before the nip, while it adheres to the first roll 12 at points ahead of the nip between the two rolls. This compression causes the web to slip on the first roll 12 near the nip in response to the compression force and causes the web to be shortened and reduced in surface speed in order to match that of the second creping roll.

The apparatus of FIGURE 1 also includes a lever mechanism 14 whereby the pressures between the rolls can be adjusted. The complex drive mechanism shown in FIGURE 1 can be simplified to include a pair of gears between rolls 12 and 13 whereby constant speed differential can be easily maintained.

FIGURES 1 and 2 show the axes of the three rolls in one horizontal plane. This is convenient, since the rolls will all deflect by their own weight giving even pressure. Rolls supported by their ends will deflect under their own weight; one might represent this diagrammatically by showing the long axis of the roll as a line with a sag or curvature. If this roll has to make contact with another roll (or any other object) with a contact between the two will also contain this sag. The ideal condition therefore would be for the "sag" line (or axis curve) of each roll to be the same so that the points of contact (along the whole line of contact) will be uniform and the pressure even along this line. The simplest way to approach this ideal condition is for the axes of these rolls to lie in one and the same horizontal plane. Where the rolls differ markedly in weight, size and material, i.e., in their deflection characteristics, other arrangements might be desirable. Here it is assumed that the rolls are roughly similar in this respect. However, it is to be understood that the rolls may be differently arranged. It also may be desirable to use a fourth roll after roll 13 to assist in causing the web to follow roll 13.

The present invention is best adapted to a given situation if the interaction between the different variables involved is understood. The adhesion force between a web and a roll is found to have time dependent and time independent components. The adhesion force obeys the equation:

\[ F_t = A + Be^{-kt} \]

Where

- \( F_t \) = The adhesion force "t" seconds after release of pressure.
- \( A \) = The adhesion force after infinite time.
- \( B \) = A constant.
- \( k = A \) constant.
- \( t \) = The time after release of pressure.

The mathematical form of the time-dependent component is what one would expect if a vacuum were to be created between the web and the surface. The term "B" could be called the maximum vacuum force and "k" the porosity factor. On low speed paper machine operation with a corresponding long time interval between pressing and creping, the effect of the term \( Be^{-kt} \) becomes negligible, but it can increase the adhesion force on high speed machines.

Adhesion force acts to hold the web to the roll face of the roll 12 in spite of a compression force which is built up. The maximum compression force which can be built up before the web buckles away from the roll is as given by the equation:

\[ F_p = F_{s} - 12mV^2/g \]

Where

- \( F_p \) = Compression force which can be applied to lbs./lin.in.
- \( F_{s} \) = Adhesion force in lbs./sq.in.
- \( r \) = Roll radius in inches.
- \( m \) = Sheet mass in lbs./sq.in.
- \( V \) = Surface velocity in ft./sec.
- \( g \) = Gravitational constant 32 ft./sec^2.

\[ 12mV^2/g \] = Centrifugal force in ft, lb./in^3.

This equation shows the competition which exists between adhesion and centrifugal forces. The importance of the latter however is very small except for sheets of very high mass on high speed machines. It is seen that the adhesion force is more effective in giving compression to the web with larger diameter creping rolls.

The values of the constants "A" and "B" in the adhesion force equation are found to be dependent upon various factors. Higher nip pressures give rise to higher adhesion forces provided the moisture content is correct for that pressure. The low moisture content webs adhere best with high nip pressures whereas high moisture content webs adhere better with lower pressures. Sheets with moisture contents below 30% adhere to roll surfaces with too little adhesion to be very effective, especially when fine creping is required. This interdependence of nip pressure and web moisture is important when attempting to design the equipment and locate it with relation to the other components of the papermaking equipment.

The above statements with regard to moisture content are applicable only to wet creping operations. A dry creping operation according to the invention will be described farther on.

The adhesion to roll surfaces was also found to be a function of the material used. Chilled iron and granite surfaces were found to have the highest adhesion forces and to be very satisfactory; rubber, while it possesses much higher frictional characteristics, has a low adhesion force.

The friction between the web and roll surface performs an important function in the process. The friction force is proportional to the area of web. For the web to compress on the surface of the first roll it must slip and hence friction limits the region of sheet compression. More important, if the compression leads to buckling of the
the sheet will have acquired the surface velocity of roll 13 and will be slipping with respect to roll 12. In this region the sheet is pressed heavily in the nip between the rolls and some of the elastic compression which occurred in region 2 becomes permanent. In region 6 the web is carried away on the surface of roll 13.

FIGURE 4 presents an example of the deformation which might occur in such a process.

Although larger rolls should be more effective, rolls at least 2 feet in diameter should preferably be used for carrying out the process according to the invention. The first roll should not be less than 8 inches in diameter and the second roll should be at least 1 foot in diameter. The two rolls which run at differential speeds must be connected together with a differential speed mechanism capable of transmitting high torque. The coefficient of friction of the web between the two rolls is high (in the order of 1) and hence the force between the rolls is of the order of the nip loading used between these rolls. Hence the drive to the first roll must be designed to transmit power to the roll of:

\[ P_1 = \frac{S_{hub} NW}{38,000} \]

Where:
- \( P_1 \) = Power to drive the first roll (H.P.).
- \( S_{hub} \) = Surface speed of the roll (f.p.m.).
- \( N \) = Nip pressure lbs./in. of roll.
- \( W \) = Length of roll.
- \( \mu \) = Coefficient of friction (approximately equal to 1).

The second roll which is run at low speed must be braked, i.e., power must be removed from it to act against the nip force. The drive must be capable of transmitting this braking power:

\[ P_2 = \frac{S_{hub} NW}{38,000} \]

Where:
- \( P_2 \) = Power to be removed by slower moving roll.
- \( S_{hub} \) = Surface speed of slower moving roll in f.p.m.

The differential speed mechanism will feed this power back to the first roll so that the power consumption of \((P_1-P_2)\) in the process will be:

\[ P_1 - P_2 = \frac{S_{hub} NW}{38,000} \]

Consider roll 12 of FIGURE 2. Its rotation relative to roll 13 is such as to oppose the force applied to the web by roll 13, i.e., it must force the sheet into the nip formed by the two rolls 12 and 13, hence, power must be applied to the roll 12 (power, that is, in addition to the usual power which is used to overcome bearing friction, etc.). On the other hand, while the two rolls rotate in opposite directions, their surfaces at the nip are moving in the same direction, therefore at the nip the surface of roll 13 moves in the same direction as the forces applied by roll 12, and thus power must be taken out of roll 13 by its own drive mechanism. That is, roll 13 in a sense is acting as a brake. Obviously then, power must be transferred from roll 12 through the web to roll 13. Because the force on one roll must equal the force on the other and since roll 13 is slower than roll 12, there must be a loss of power corresponding to the difference in surface speeds. If the rolls are rigid and cannot deform, then it is the web that deforms and this work goes into rearranging the fibrous components of the paper web.

The relative speeds of the machinery preceding and following the creping apparatus must be such that the paper after creping will be moving at slower speed. This slower speed should be slightly higher than the surface speed of roll 13 since a small part of the compression will be pulled out in pulling the web from the roll 13.
The nip pressures to be employed for the process can be varied to obtain the required paper properties to compensate for such factor as moisture content. The pressure at the nip of the rolls 11 and 12 pressing the web onto the first roll 12 influences the adhesion and friction of the web on the roll surface or crepe. The pressure between the two differential speed rolls influences the pressing in of the crepe product and hence the flatness and mechanical properties of the finished sheet.

The roll surfaces of rolls 12 and 13 should be such as to give maximum adhesion and friction if the finest crepe with maximum nip resistance to stretching is desired. The surfaces should have a fine finish for best adhesion and friction so as to enable the web to slip over the surface without breaking the adhesive bond. Roll 13 should have a slightly higher adhesion and friction than roll 12 (with relation to the web) so that the web can be forced to follow 13. This may be accomplished by a proper selection of roll materials or the nature of the roll surfaces or, as mentioned above, by maintaining the rolls at a different temperature or moisture level. For example, using polished iron rolls for roll 12 and roll 13, roll 12 may be steamed heated from the inside and roll 13 water cooled from the inside.

Referring to FIGURES 1 and 2, the auxiliary transfer roll 11 should generally be of a soft material such as rubber so that the wet web can be pressed evenly onto the first roll 12. Alternatively, a simple wet felt carrying the web may be used to press the web against the first roll. The first roll 12 may be either of hard or soft elastic material, whereas, the second roll 13 should be of hard material.

If a hard material is used for roll 12, the surface of the roll cannot distort and as result shear will occur in the nip. As mentioned the adhesion and friction properties of rolls 12 and 13 should be such that the slippage as a result of the shear at the nip centre occurs between the web and roll 12 rather than between the web and roll 13 so that the web on the outgoing side of the nip will follow roll 13. The shear which occurs gives rise to some displacement in the web itself, moving fibres which are not well bonded so that better ultimate strength properties can be achieved. The strength of a sheet can be related to its bonded area, i.e., to the area of contact between the individual fibres. If a sheet is compacted by moving fibres together, more points of contact are created (or the bonded area increased), so that one can assume that after a pressing operation as takes place in the nip (between roll 12 and 13), following this fibre moving, that the moist or dried web will have better strength properties than would be otherwise possible.

If soft, elastic rubber material is used for the first roll 12, the action is quite different. The rubber has a high coefficient of friction but low adhesion to the wet web, hence the surfaces of the differential speeds between rolls 12 and 13 the surface of rubber roll 12 will be slowed down ahead of the nip in the regions described in FIGURE 3 as regions 2, 3 and 4, so that the surface speed in region 5 will match that of roll 13. On the outgoing side of the nip, the rubber surface will be in the stretched condition, because of the braking effect of roll 13. As a result of this, the web will not slip on the surface of roll 12 as it approaches the nip, but will compress with it and because of low adhesion there will be a tendency for a coarser crease than would be the case for a hard roll. There will also be no shear at the nip centre as the surface speed of both rolls will be that of roll 13. On the outgoing side of the nip the rubber surface of roll 12 will suddenly snap back to its normal unstressed position so doing it will tend to free the web and allow it to follow roll 13.

Thus, while the aforementioned creping process is operable using soft, resilient surfaces for the first roll 12, the use of such surfaces is somewhat limited to the extent that its surface deformation characteristics are able to compensate for its relatively high friction characteristics. In the case of hard, relatively non-deformable surfaces, compression apparently takes place not through surface pressure but through a combination of shear and surface slippage of the web on the faster-moving roll 12.

The proper selection of material for the surfaces of rolls 12 and 13 is therefore an important consideration when using the method according to the invention. The actual choice, however, depends on what effect that the paper properties desired in the final product.

The compression process can be carried out at varying moisture content through appropriate adjustment of nip pressures between the rolls. Difficulty will be encountered however when attempts are made to carry out the process with less than 50% water content in the paper web. Even for webs of this moisture content to develop differential stresses which cause them to wrinkle and cockle so that it is difficult to make them adhere properly to a surface. On the other hand, if the process is carried out when the web is too wet, the compression may pull out in later drying, since the web will be delaid from the dryer cylinder. This would cause the sheet to slip on the dryer cylinder. Thus, while the aforementioned creping process is operable using soft, resilient surfaces for the first roll 12, the use of such surfaces is somewhat limited to the extent that its surface deformation characteristics are able to compensate for its relatively high friction characteristics. In the case of hard, relatively non-deformable surfaces, compression apparently takes place not through surface pressure but through a combination of shear and surface slippage of the web on the faster-moving roll 12.

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of paper adheres to the second roll after passage through the nip.

11. A method as defined in claim 8, wherein the second roll has a higher coefficient of friction than the first roll.

12. A method as defined in claim 8, wherein the axes of rotation of the two rolls are horizontal.

13. A method as defined in claim 8, wherein the axes of rotation of the two rolls lie in a horizontal plane.

14. A method as defined in claim 2 wherein adhesion of the moving web of paper to the rotating first roll is controlled by controlling the temperature of the first roll.

15. A method as defined in claim 2 wherein the relative temperatures of the first and second rolls are controlled.

16. A method as defined in claim 2 wherein the relative surface wetness of the first and second rolls is controlled.

17. Apparatus for the manufacture of crepe paper comprising a first roll, a second roll forming a nip with the first roll through which a web of paper may be passed and compressed simultaneously in two directions, one direction being that in which the paper is travelling and the other being that perpendicular to said direction of travel, the surface of said first roll being non-resilient and characterized in that said web will slip on said first roll when said web is compressed in said two directions, the surface of said second roll being non-resilient and characterized in that said web will not slip on said second roll but will adhere preferentially to said second roll when said web is compressed in said nip and shortened and reduced in surface speed in order to match the surface speed of said second roll and will pass out from said nip and adhere to said first roll, drive means adapted to rotate said rolls in mutually opposite directions at speeds such that the peripheral speed of said second roll is less than that of the first roll, and means adapted to control the nip pressure between said first and second rolls.

18. A method of manufacturing crepe paper comprising causing a moving web of paper having a moisture content between 30% and 80% of the weight of the wet web to adhere to a first cylindrical roll having a diameter of at least 8 inches passing the web through a nip formed between said first roll and a second cylindrical roll having a diameter of at least 1 foot, said second roll rotating in a direction opposite to the direction of rotation of the first roll and having a lower peripheral speed than the first roll, the web being pressed between the rolls as it passes through the nip, and causing the web of paper to be freed from adherence to the first roll after passage through the nip, the surfaces of said first and second rolls being non-resilient.