Mechanization of Tea Leaf Handling in Trough Withering System

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ABSTRACT

Leaf handling in the first stage of black tea manufacture, viz. withering (dehydration of leaf up to a desired level), is heavily manual labour intensive, although the subsequent stages, viz. leaf-cell distortion, polyphenol oxidation (fermentation), and drying or firing; and also post-manufacturing operational phases sorting and grading, as well as packing, have long been mechanized and made continuous in sequence of operations through conveyor connectivity. Manual handling of tea leaf for withering is not only labour intensive, but also causes damage to fresh tea leaf and degradation to made tea quality. If tea leaf handling in withering were mechanized it could reduce fresh leaf damage and retain or improve made tea quality. With a view to mechanize the leaf handling operations involved in trough withering system, a conceptual functional design of a mechanical system was hypothesized and accordingly a physical working model of the system was developed, which was found to be quite effective in doing its intended functions, i.e., spreading of fresh tea leaf uniformly over the trough bed;, unloading of withered tea leaf from the trough bed; and shifting of the same up to a leaf distorting machine (eg, a rotorvane) for next-stage operation(s). The system, which was developed primarily for a single withering trough, could be easily extended to a number of withering troughs to form a unified mechanical loading-unloading cum withered-leaf shifting system for several withering troughs for industrial application. The present paper provides concept and physical descriptions as well as performance of the mechanical system.

Keywords: Tea leaf; trough withering; withering trough; leaf handling; mechanization; belt conveyor; intermittent motion.

1. INTRODUCTION

Conventional tea manufacturing processes are labour intensive and inefficient. The most labour intensive and inefficient manual operations involved in tea manufacturing are handling of tea leaf in the first stage, viz withering. Withering refers to the changes (physical and chemical) that occur in tea leaf from the time it is detached from the plant to the time of maceration (Owuor and Orchard, 1989). Physical withering is moisture loss of fresh tea leaf and related physical changes, while chemical withering involves biochemical changes, which depend on time, and are independent of moisture loss (physical withering). For practical purpose, withering is often meant for dehydration (through forced or natural air) of fresh tea leaf brought about up to a desired level in the tea manufacturing yard or factory. Excessive manual handling of green tea leaf in normal withering practices invariably causes damage to tea fresh leaf and consequent degradation to made tea quality. Thus, automation (mechanization) in leaf handling assumes urgency (Punshi, 1984) in order to reduce leaf damage and retain or improve tea quality. Tomlins and Mashingaidze (1997) opined after extensive survey of tea literature that reduced manual handling of tea leaf in mechanized withering might improve quality of made tea.

Among different withering systems, the trough withering system, using a withering trough as the withering equipment, has become very popular and is widely used in many tea countries including India. Between two types of withering troughs, the enclosed type has outweighed the earlier developed open type in merits and is more commonly used. However, in either type, loading of fresh tea leaf on the withering trough bed, and unloading of the withered tea leaf from the trough bed, as well as shifting of the same up to a leaf-cell distorting machine (e.g., rotorvane) for the next-stage operation on it, are still done manually. Thus it was a research objective to design and develop a mechanical system for mechanization of manual operations associated with trough withering of tea leaf. In absence of any prior procedure or exemplary system for such mechanization, it was thought prudent to hypothesize a concept and functional design of a mechanical system and accordingly develop a physical model of the system and test for its effectiveness and performance in accomplishing the intended functions, and to judge its prospective industrial utility for the desired mechanization.

2. REVIEW OF LITERATURE

From review of literature, only one instance of an effort to mechanize the withering trough loading was known. Wemyss (1973) reported that three engineering firms in Kenya, under patronage of Sotik Tea Company Limited, together developed a machine for mechanical loading of withering troughs. The electronically operated hydraulically driven wheeled loading machine, being fed with few quintals fresh green tea leaf at its outset, moved on heavy rails placed over the stationary withering-trough beds and spread the leaf on the beds in multiple passes. In order to feed the machine, an elevated roadway running at a height of top of the hopper was constructed. Green leaf containing bags, transported on trailers or lorries, had to be tipped by hand into the machine's hopper from this elevated roadway by several persons. This cumbersome loading machine for withering troughs was of considerable size and weight, the driver also sat within it, and it thus imparted enormous wheel loading on the rails and supporting structures over the trough beds; and therefore the inventors suggested its use on ground floor only, and proposed to demolish all multi-storied withering houses, probably under the presumption that land was never a limiting or costly factor.

However, this machine was meant only for loading of withering troughs; the post-withering unloading of the withering troughs and shifting of the unloaded withered leaves up to a leaf-cell distorting machine had to be done still manually. So, complete mechanization of the trough withering system, and its integration with the post-withering mechanized and operationally connected continuous stages, were far from achievement.

3. THEORETICAL CONCEPT AND FUNCTIONAL DESIGN

The following concepts and functional design principles for a mechanical loading-unloading cum withered-leaf shifting system for a withering trough were adopted as first theoretical basis towards perspective mechanization of the trough withering system.

3.1 Feeding of Fresh Tea Leaf

Fresh tea leaf would be continually fed through a feeding hopper and a belt feeder (Fig. 1) onto a belt conveyor that would supply the leaf to a leaf spreading machine placed on guide wheels on a pair of rails laid above and across the trough bed at its front end.
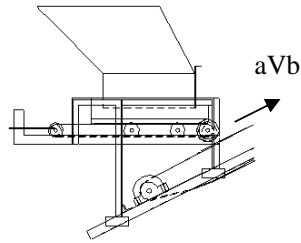
Figure 1. Feeding of leaf through a hopper and a belt feeder

Leaf fed per unit time (kg/s) onto the slant belt conveyor would be given by (Brook, 1971)

$$Q = a\,V\,b \qquad\qquad\qquad \text{... (1)}$$

where

      a cross-sectional area of fresh tea leaf fed on leaf supplying conveyor belt, m^2

      b average bulk density of fresh tea leaf, kg/m^3, and

      V linear speed of leaf- supplying belt conveyor(s), m/s.

3.2 Scraping of Conveyed Tea Leaf

The fed leaf would be conveyed by an overhead horizontal belt conveyor, wherefrom it would be scraped into the hopper of the leaf spreading machine by means of a leaf scraping flight belt conveyor fixed with the framework of the leaf spreading machine which would be continually reciprocated on rails above and across the trough bed at its front end.
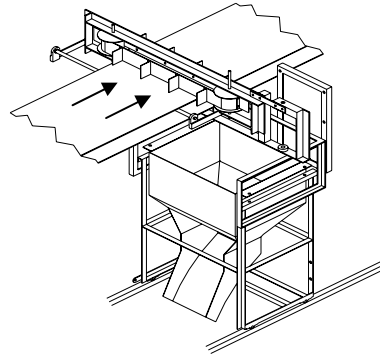

Figure 2. Leaf scraping into the leaf spreading hopper

For proper scraping of leaf without overflow, heights of flights of the leaf scraping flight belt conveyor would be $h_f \geq 0.7\,h_o$, where h_o is the height of outlet of the feeding hopper over the belt feeder (taking outlet width $w_o \geq 2.5\,h_o$, and 39.5^o dynamic angle of repose for fresh leaf).

If width of each flight were w_f, then the linear speed v_{fb} of the flight belt conveyor must be such that $aV < h_f\,w_f\,v_{fb}$. And, for continuous scraping of the leaf mass by means of the flight belt conveyor always of a cross-section similar to its flights (blades), spacing between two adjacent flights s_f should be such that $h_f < s_f \leq 2\,h_f$.

3.3 Spreading of Tea Leaf

The leaf spreading machine would consist of a spring-suspended vibrating hopper (Fig. 2). Necessary vertical vibration to the hopper would be imparted through a crank mechanism.

The leaf-spreading machine would be given continuous reciprocating motion on rails above and across the trough bed, by means of a dc motor with a specially designed control circuit. The trough bed would be an intermittently movable wire-mesh belt conveyor, run by a dc motor with a specially designed control circuit. Leaf would be continually spread by the reciprocating leaf spreading machine in individual strips of multiple layers over and across the trough bed (mostly) during its intermittent idle period. After a complete strip is spread, the bed would be advanced by a distance equal to average width of the strip, and stopped for spreading the next strip. This sequence would be continued until the whole trough bed would be spread with tea leaf.

Mathematically, speed of reciprocation (m/s) of leaf spreading machine,

$$v_m = 2w_{tb} / T_c \qquad \qquad \text{… (2)}$$

And, time (s) required for spreading a complete strip of tea leaf,

$$t_s = (1/2)n_p T_c \qquad \qquad \text{… (3)}$$

where,

w_{tb} effective width of trough bed, m
T_c reciprocation cycle of the leaf spreading machine, s
n_p number of passes (half-cycles) of the leaf spreading machine above and across the trough bed to spread one complete strip

The quantity (kg) of leaf spread per strip would be

$$Q_s = (1/2)n_p T_c aVb \qquad \qquad \text{… (4)}$$

If L_{tb} is effective length of trough bed, in m, and w_s is average width of one complete strip of spread tea leaf, in m, then number of strips to be spread across the trough bed would be given by

$$n_s = L_{tb} / w_s \qquad \qquad \text{… (5)}$$

Total quantity, kg, of leaf spread (loaded) on trough bed would be given by

$$Q_l = (1/2)n_p L_{tb} T_c aVb / w_s \qquad \qquad \text{…(6)}$$

Depth in m of spread leaf mass would be given by

$$d_s = (1/2)n_p T_c aV / w_{tb} w_s \qquad \qquad \text{… (7)}$$

Total time in s required to spread the whole area of the trough bed would be

$$t_t = (1/2)n_p T_c L_{tb} / w_s \qquad \qquad \text{… (8)}$$

If t_i (s) is interval or idle time of the intermittently running trough-bed driving motor and t_r (s) is its intermittent run time, then the time, in s, required to spread one complete strip of leaf is

$$t_s = t_i + t_r \qquad\qquad\qquad \ldots (9)$$

During time t_i the trough bed will remain stationary to receive most of the leaf spread in a complete strip. In t_r s the bed will advance by a distance equal to average width of a strip, ie w_s. The run time of motor, t_r, should be kept as small as practicable.

3.4   Unloading and Shifting of Withered Tea Leaf

For unloading, the trough bed would be given slow and steady reverse motion, so that the withered leaf would fall on a withered-leaf collecting cum shifting belt conveyor placed in front of the trough bed little below its horizontal level.

Then, quantity of withered tea leaf unloaded (and shifted) per unit time ($\dot{Q}_u$) in terms of mass (kg) would be given by

$$\dot{Q}_u = w_{tb}\, d_{wl}\, v_b\, b_w \qquad\qquad\qquad \ldots (10)$$

where

b_w bulk density of withered tea leaf, kg/m^3
d_{wl} average depth of withered tea leaf on trough bed, m
w_{tb} effective width of the trough bed, m, and
v_b backward speed of the trough bed during unloading, m/s

4. MATERIALS AND METHODS

According to the concept and working principles laid down in section 3, a physical working model of a mechanical loading-unloading cum withered leaf shifting system for a withering trough was fabricated and developed. Description of the developed mechanical system is given below with reference to its labeled isometric drawing views in figures 3(a) and 3(b).

Fresh tea leaf collected from field is first kept on a platform (1) on [or below] which the lower end of a slant belt conveyor (2) rests. The leaf is fed onto the leaf-supplying slant belt conveyor (2) through a belt feeder. The slant belt conveyor (2) conveys the leaf to the horizontal belt conveyor (3) over and across which a vertically positioned leaf scraping flight belt conveyor (4), fitted with the leaf spreading hopper's (5) frame, is extended to scrap the leaf by its handles or flights down into the leaf spreading hopper. The slant and the horizontal leaf-conveying belt conveyors are run by a controllable-speed dc motor (10). The leaf spreading hopper (5), along with its wheeled framework, is given continuous reciprocating motion on two rails (6) placed above and across the trough bed near its entrance end by means of a variable speed dc motor (8) controlled by an electrical control circuit (16) [circuit diagram and description are provided in Appendix I]. The leaf spreading hopper (5) is also given vibration by means of a crank mechanism run by another small dc motor (9) placed on its frame. This second motor (9) is also used for giving motion to the leaf scraping flight belt conveyor (4). The vibrating and reciprocating leaf spreading hopper (5), being placed below the horizontal leaf-supplying belt conveyor (3), gets supply (feed) of tea leaf all the time irrespective of its different locations on the rails (6) and shuffles and sprinkles the tea leaf on the perforated trough bed (12) placed below it. The trough bed (12) is made of wire-mesh netting, wrapped around and movable on end rollers or pulleys, just like a belt conveyor.
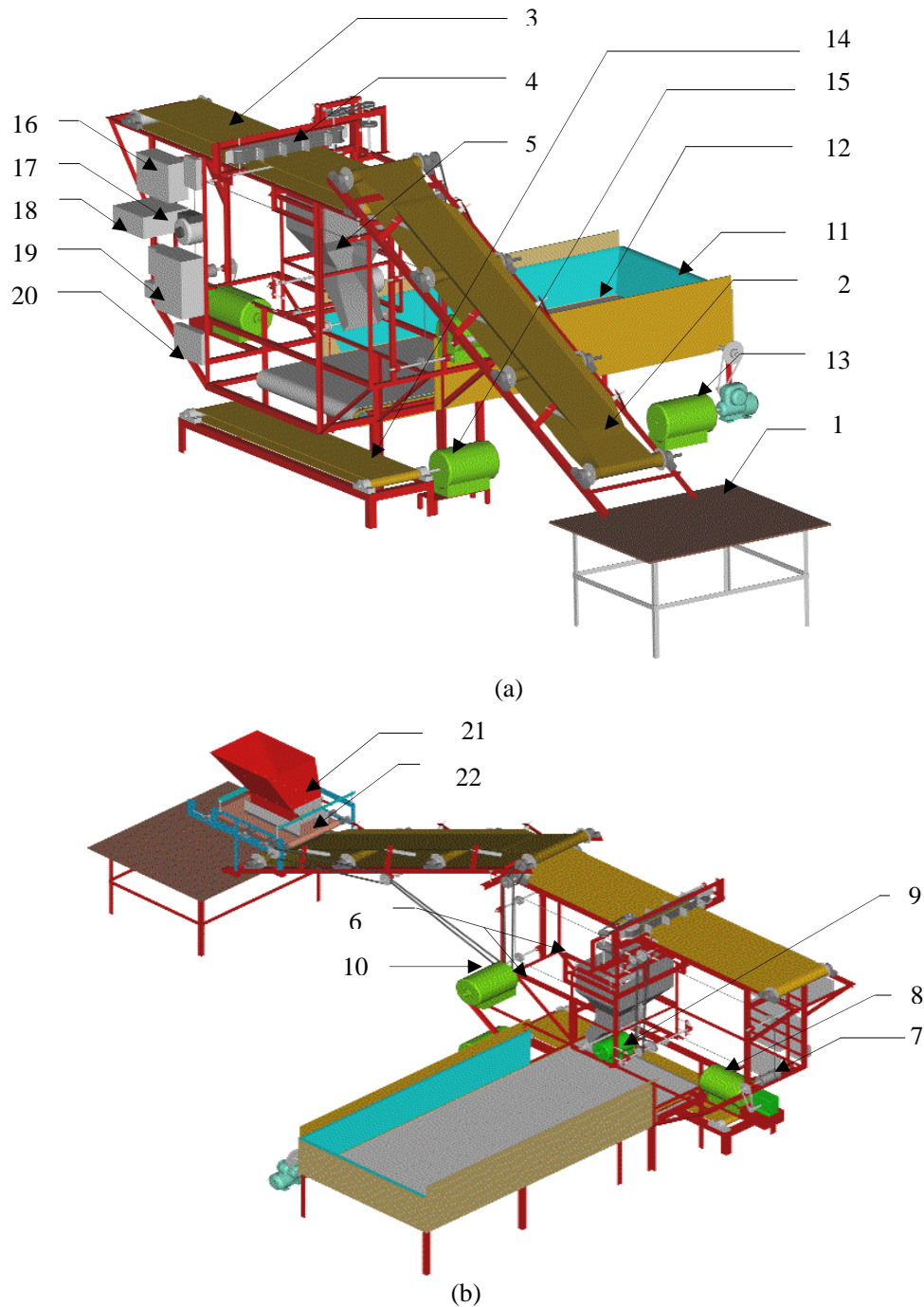
(a)

(b)

Figure 3. The mechanical loading-unloading system for a withering trough (a) without belt feeder; (b) complete with a belt feeder: (1) leaf dumping platform, (2) slant leaf-supplying belt conveyor, (3) overhead horizontal leaf-supplying conveyor, (4) leaf scraping flight belt conveyor, (5) leaf spreading hopper, (6) rails above and across the trough bed, (7) drum (attached with rope over pulleys) to impart reciprocation to hopper assembly, (8) motor for reciprocation of spreader hopper, (9) motor for leaf scraping belt conveyor & hopper vibration, (10) motor for leaf supplying belt conveyors, (11) trough, (12) trough be, (13) motor to drive the trough bed, (14) withered leaf collecting cum shifting belt conveyor, (15) motor for leaf collecting cum shifting belt conveyor, (16) box of control-circuit for the reciprocating motor, (17) autotransformer to control speed of reciprocating motor, (18) box of control-circuit for the intermittent motor, (19) speed control unit of the motor for leaf scrapper and spreader, (20) electrical circuit board, (21) hopper of belt feeder, (22) belt of the belt feeder.

The leaf spreading hopper assembly on the rails above the trough bed is allowed to continuously reciprocate and spread (sprinkle) tea leaf on the trough bed in a strip of width as much as the hopper outlet width. The trough bed is kept stationary until a certain height of a strip of tea leaf is obtained. Then the bed is moved forward by a distance equal to the average width of the strip, and then stopped for spreading another strip of the same height adjacent to the previous strip, and then again moved by a distance equal to the average width of the strip. In this fashion the operation is continued until whole area of the trough bed is spread with fresh tea leaf up to a certain spread depth all along. A limit switch connected with electrical control circuit [diagram and description are provided in Appendix II] of the trough bed driving dc motor (13) causes termination of the spreading (loading) operation.

For unloading of the withering trough, after withering of tea leaf for about 14 to 16 h, the trough bed is given continuous slow motion in backward direction, as a result of which the withered tea leaf falls on a withered leaf collecting cum shifting belt conveyor (14), which is placed in front of the trough bed slightly below its level, and run by a dc motor (15).

A photographic view of the developed mechanical loading-unloading cum withered leaf shifting system is provided below in figure 4.

Figure 4. The developed model of mechanical loading-unloading cum withered-leaf shifting system for a withering trough

It should be mentioned that not a whole withering trough, but only the endless-conveyor type movable bed of a withering trough was essential to demonstrate the mechanical loading and unloading operations by the developed mechanical system. Therefore, a complete withering trough with walls, ceiling, trough bed, aeration chamber, dampers, alternate air exits, etc was not made in the developed model; only the wire-mesh belt conveyor in the trough bed along with some sections of the attached walls was made, as may be seen in figures 3 and 4. Mild steel angle irons, flats, and pipes were widely used in fabrication of framework of the system.

5. RESULTS AND DISCUSSION

5.1 Performance of the Developed Model of Mechanical System

The model of the mechanical system, designed and developed with a view to uniformly spreading (loading) tea leaf in a withering trough, with provisions for unloading and withered leaf shifting as well, was tested for its loading performance, regarding uniformity in spreading, reproducibility of similar loading, loading time, and loss of leaf while loading, etc. Unloading and withered leaf shifting performance was not evaluated for the absence of a leaf distorting machine whereto the leaf could be steadily shifted.

Tests for uniformity of tea leaf spreading, based on both mass of leaf spread per unit (1 m^2) area and on spread depth, by the mechanical system were carried out, taking the data at six cross-sections along the length of the trough bed. On statistical variance analysis it was found that there were no significant differences among the data at those points in different similar spreading/loading experiments. This may be observed in figure 5 as well. Thus it was found that the developed loading system was capable of spreading tea leaf uniformly, in terms of both mass of leaf spread per unit area and spread depth.
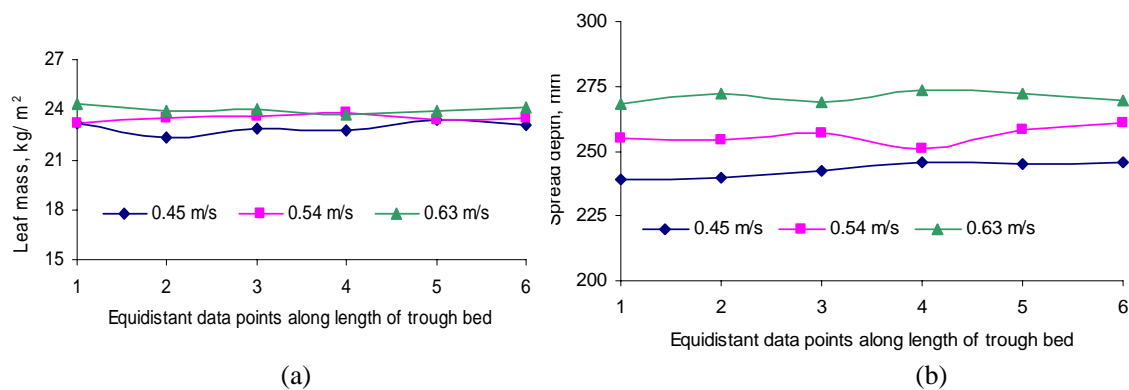

Figure 5. Uniformity of tea leaf spreading by the mechanical system at different speeds of the leaf-supplying belt conveyors: (a) on mass per unit area basis, (b) on spread depth basis; the legends shown are three different speeds of the leaf-supplying belt conveyors

However, for comparative purposes, values of defined uniformity index I_u (adapted from Michael, 1997; $I_u = 100(1.0 - \sum d / \bar{x} n)$, where $\bar{x}$ is arithmetic mean of all the observations, n is total number of observations, d is numerical deviation of individual observations from the mean $= |x_i - \bar{x}|$, x_i is individual observation) for the pertinent data from each of the uniformity of mechanical spreading tests were calculated, and those were compared with I_u values for the uniformity of manual spreading tests, which were done in two tea factories of two tea estates in Assam. I_u values based both on mass of leaf per unit (1 m^2) area and on spread depth in case of mechanical spreading by the developed mechanical system were always above 93.10% (up to 97.75%); whereas I_u for the uniformity of spreading tests on corresponding bases in case of manual spreading in tea factories were always below 91.25% and as low as 87.49%. Thus, uniformity in mechanical spreading of tea leaf by the mechanical system was always better than that in manual spreading.

From uniformity of mechanical spreading test data, time periods needed for unit discharge (one kg leaf spreading) were calculated. In order to check reproducibility of similar spreading (loading) at similar conditions by the system, it was checked whether there were significant differences among the different time periods. The factor means of time periods for unit discharge differed non-significantly for each particular leaf-supplying conveyor-belt-speed (0.45, 0.54, or 0.63 m/s); but, although the means of the time periods per unit discharge for two belt-speeds of 0.45 and 0.54 m/s varied non-significantly, the means for a higher speed of 0.63 m/s differed significantly. This implies that for each specific setting of the leaf-supplying conveyor-belt speed, the system can produce similar spreading in different loading trials; and the belt speeds may have significant effect on time period per unit discharge, or on total leaf mass spread within a particular time period. However, it was felt that for ensuring invariable reproducibility of similar loading, a stable-rpm geared motor should be used.

The mechanical system was capable of spreading the 2.35 m x 0.98 m trough bed area within two minute 15 s. There was negligible loss of tea leaf - hardly 0.4% of the total leaf spread - by side-spills from conveyor belts. The witherered-leaf unloading cum shifting performance of the developed model could not be quantitatively measured because of non-existence of sequential arrangement of machines and equipment for subsequent processing operations on the leaves, nonetheless the unloading cum shifting arrangement of model was sufficient to demonstrate effectiveness of the mechanical system in performing these operations as well.

5.2   Means of Extension and Design for Industrial Application

To extend the mechanical loading-unloading cum withered leaf shifting system to a number of (2 to 10, or more) withering troughs placed in parallel, it would be necessary first to make the trough beds as movable perforated (wire mesh) belt conveyors; to extend the overhead horizontal belt conveyor and the rails, which support the leaf spreading machine, over the trough beds; and to extend the 'withered leaf collecting cum shifting belt conveyor' ahead of all the trough beds, below their horizontal levels. With this arrangement, a single leaf-spreading machine would be used to spread fresh tea leaf on all the trough beds, in turn, each time by using the same pair of easily-shiftable limit switches to confine reciprocation of the leaf-spreading machine on rails over the particular trough bed. For unloading, it would be necessary to provide slow and continuous motions to the trough beds, in turn, in the reverse direction, and simultaneously to run the withered leaf collecting cum shifting belt conveyor to shift the unloaded withered leaf to a leaf-distorting machine.

Design specifications and calculations for different components of a unified mechanical system for several withering troughs can be made mainly on the basis of (i) proposed arrangement of the components in the multi-withering-trough system, (ii) reference to organization of different components of the system in the developed laboratory-scale model, (iii) Indian standard specification for pulleys for belt conveyors (ISI, 1987), (iv) Indian standard specification for idlers and idler sets for belt conveyors (BIS, 1988), and (v) belt conveyor design procedure provided by Conveyor Equipment Manufacturers Association of USA (CEMA, 1997). Based on the mentioned techniques and means, Das (2004) has presented an illustrative design procedure for a unified mechanical loading-unloading cum withered leaf shifting system for ten factory-scale withering troughs, each of effective bed size 27.4 m x 1.83 m, within a typical withering plant of size 35 m x 30 m.

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7. APPENDICES

Appendix I: Control circuit for reciprocation of the leaf-spreading machine driving dc motor

To meet the essential requirement of producing the necessary reciprocating motion for the driving motor of the leaf-spreading machine on rails above and across the trough bed, a dc-motor control circuit was designed, diagram and description of which are provided hereunder.
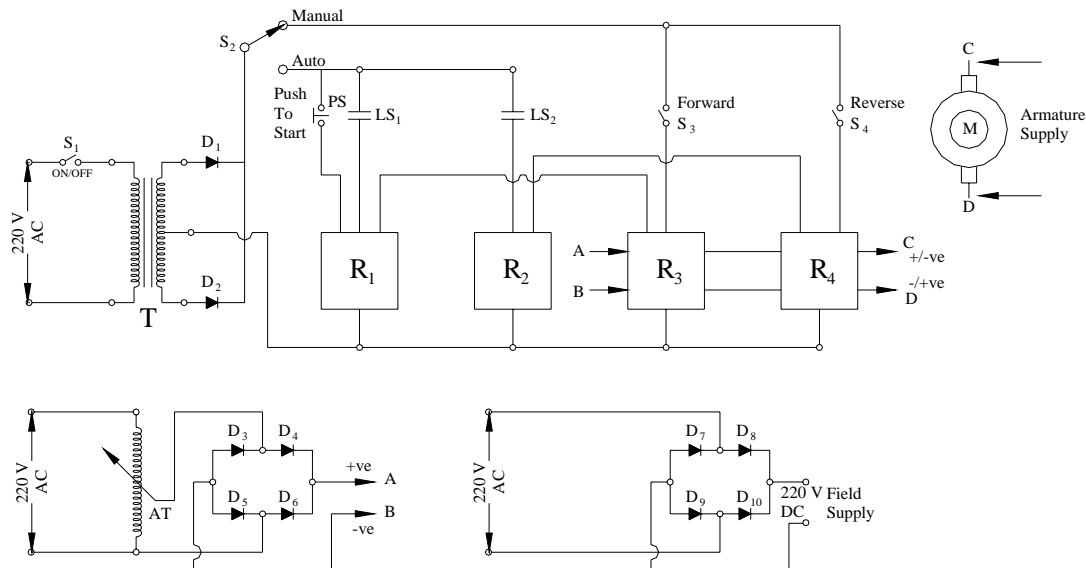

Figure 6. Control-circuit for leaf-spreading machine driving dc motor for continuous reciprocating motion: S, switch; LS, limit switch; PS, push switch; D, diode, T, transformer; AT, autotransformer; M, motor; R, relay.

When power switch is put on, the ac single-phase 220 V supply gets converted by a bridge converter circuit (rectifier), consisting of 4 diodes, D_7, D_8, D_9, and D_{10}, to dc 220 V, which is applied across the field terminals of the dc motor (lower-right diagram). In a separate power tapping (lower-left diagram), when the ac single-phase 220 V supply is applied across the two terminals of the autotransformer (AT), the transformed (stepped down) output voltage passes through a bridge rectifier, consisting of 4 diodes, D_3, D_4, D_5, and D_6, which converts the ac supply power to dc power at the two terminals, A and B, marked with +ve and –ve, respectively, which in turn are connected across the terminals of the armature windings of the dc motor through the two relays, R_3 and R_4, which alternately changes polarity (+ve to –ve, and vice versa) of the two terminals, C and D, depending on stimulations imparted to these two relays from the main circuit (upper-left diagram), and thus alternate forward and reverse motions of the motor armature and shaft is obtained..

When the power switch S_1 (upper-left diagram) is put on, ac 220 V single-phase supply is applied to primary of the centre-tapped transformer (T). The stepped-down output ac voltage gets converted to dc voltage by the half-bridge rectifier consisting of two diodes D_1 and D_2, and this converted dc voltage becomes available at the single-pole double-throw (SPDT) switch S_2, which can be given connection to either manual mode or automatic mode.

(i)   *Manual mode to obtain the reciprocating motion*

When the manual mode is set on, the forward or reverse motion obtainable would depend on which of the Forward and Reverse switches (S_3 and S_4) is pressed to its 'on' position. When the forward switch is put on, relay R_3 is energized and, according to the circuit arrangement as shown, forward motion is obtained. And, when the Forward switch (S_3) is kept off and the Reverse switch (S_4) is put on, relay R_4 is energized and, according to the circuit arrangement, reverse motion is obtained.

(ii)   *Automatic mode to obtain the reciprocating motion*

When the 'Auto' mode is set on, and the Push To Start switch (PS) is once pressed in order to start the operations, the main circuit (upper-left diagram) automatically gives alternate forward and reverse motions, as would be accentuated by the two limit switches, LS_1 and LS_2. When a pointer attached with the frame of the leaf spreader hopper, which is to be reciprocated on the rails, strikes against the limit switch LS_1, switch LS_1 gets activated, relays R_1 and R_3 get energized and, according to the circuit arrangement, forward motion of the motor shaft is obtained and retained until another pointer attached on the opposite side of the frame of the leaf spreader hopper strikes against the limit switch LS_2, when LS_2 would be activated, relays R_2 and R_4 would get energized, and as a result, according to the circuit arrangement, reverse motion would be obtained and retained until the opposite pointer on the frame of the hopper would again strike against the limit switch LS_1; switch LS_1 would be activated, switch LS_2 would be deactivated, relays R_1 and R_3 would get energized and forward motion of the motor shaft would be again obtained and retained until the pointer attached on the opposite side of the frame of the hopper strikes against the switch LS_2, when again reverse motion would be obtained, and so on. In this way, continuous reciprocating motions for the leaf spreader hopper would automatically be obtained between the two pints on the rails, as marked by the two limit switches LS_1 and LS_2 fitted at those points on the rails.

The two limit switches, connected with the control circuit and clamped on the rails, served the purpose of confining reciprocation of the leaf-spreading machine on the rails in between two points determined by the machine's allowable extreme positions on the rails while it was spreading the leaf on the trough bed.

Appendix II: Control circuit for the intermittently movable trough-bed driving dc motor

A dc-motor control circuit was specially designed and developed for the trough- bed driving dc motor in order to produce necessary intermittent motion in forward direction and continuous steady motion in the reverse. Diagrams of the control circuit and accessories have been provided below in figure 7; descriptions of the same follow.
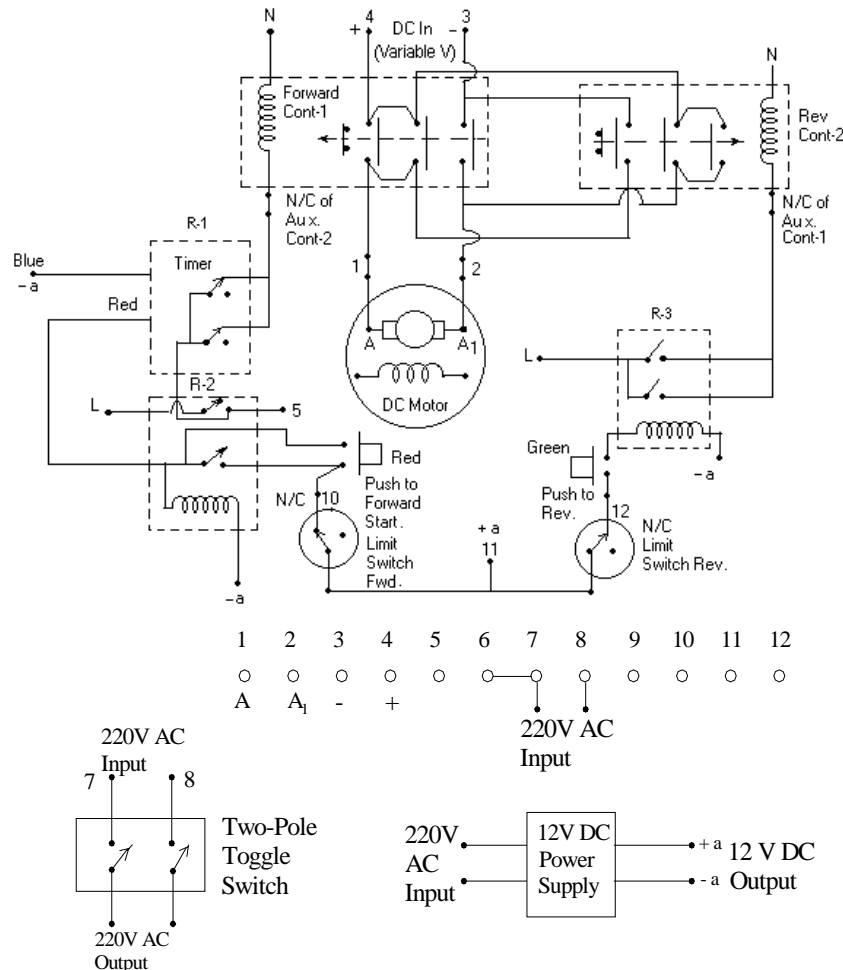

Figure 7. Control-circuit diagram for trough-bed driving dc motor used for intermittent forward- and continuous reverse motion: 1, 2, ..., 12, external terminals; A, A_1, armature terminals; Cont., contactor; L, line; N, neutral; N/C, normally closed; R, relay

AC 220 V supply is directly connected to terminals 7 and 8 and to the 'dc motor power-supply cum speed-control unit' (readily procured, external to the control circuit). When the power switch is put on, a bridge rectifier in the power-supply cum speed-control unit converts the ac 220 V to dc 220 V, which is applied across the field windings of the motor. The ac 220 V available in power-supply cum speed-control unit is separately transformed by an autotransformer within the unit. The variable ac output voltage (0 to 220V) gets converted by another bridge rectifier to variable dc voltage, which is applied across terminals 3 and 4. This variable dc voltage available at terminals 3 and 4 is then taken through Forward Contactor (Cont-1) or through Reverse Contactor (Cont-2) to terminals 1 and 2, or equivalently to terminals A and A_1 of armature windings of the motor. The reversal of direction of rotation of

the dc motor is obtained by changing polarity of armature terminals of the motor utilizing the forward contactor and the reverse contactor alternately. Speed of the dc motor would be determined by the magnitude of the armature input voltage (0-220V) obtained by various settings of the autotransformer. Forward or reverse direction of motion would depend on which one of the forward and reverse contactors is made operative. In order to control operations of the Forward Contactor (Cont-1), a timer circuit, two relays (R-1 and R-2) and a limit switch were used; and, to control operations of the Reverse Contactor (Cont-2), a relay (R-3) and a limit switch were used. The dc 12 V power necessary to operate all these relays, timer circuits and limit switches is obtained from a '12 V DC Power Supply', which gets ac 220 V input from terminals 7 and 8 and produces dc 12 V output, available across +a and –a.

(a)   *Obtaining intermittent forward motion*

If the "Push to Forward Start" switch is pushed once, the relays R-2 and R-1 and the timer circuit will be activated to control operations of Forward Cont-1. As long as the timer circuit will allow the coil of contactor 1 (Cont-1) to get energized, the activated coil will cause closure of all the contacts of the contactor (but will open the normally close contact of auxiliary contactor 2), thus making straight paths for the power to be transmitted from terminals 4 (+ve) and 3 (-ve) to terminals 1 and 2, thereby imposing positive and negative polarity to terminals A and A_1, respectively, and producing the forward motion.

But as soon as the timer circuit will (temporally) break the power circuit with the coil of contactor 1 (Cont-1), all the contacts of contactor 1will get dislodged and no power will be transmitted from terminals 3 and 4 to terminals 1 and 2, or to armature terminals A and A_1, and so there will be (temporarily) no motion of the armature or the motor shaft (ie, intermittent stop condition), until again the timer circuit allows the coil of contactor 1 to get energized, and thus again producing forward motion (run). The run time and stop (idle) time can be set to desired values by selecting suitable values of the variable resistors (potentiometers) of the timer circuit. Intermittent forward motion thus obtained will continue until the red push switch is not pressed again or a terminator pointer does not strike the Forward Limit Switch in order to break the circuit involving the relay R-2.

(b)   *Obtaining continuous reverse motion*

When power is already available across the field windings of the motor and also at terminals 3 and 4, if the green "Push to Reverse" switch is pressed and kept pressed, relay R-3 will be operative and as a result all the contacts of contactor 2 (Cont-2) will be closed, (but the normally closed contact of auxiliary contactor 1 will be opened), thus making round paths through Cont-2 for the power to be transmitted from terminals 3 (-ve) and 4 (+ve) to terminals 1 and 2, respectively, thereby imposing negative and positive polarity to terminals A and A1, respectively, and producing the reverse motion. This reverse (backward) motion will continue as long as the green push switch is kept pressed, but if the switch is released or if the terminator pointer strikes the Reverse Limit Switch, the circuit involving the relay R-3 will break, and no motion would be obtained.

The two limit switches, connected with the control circuit and clamped beside the trough bed at the extreme ends of its effective working length, were used to confine movements of the wire mesh conveyor belt in the trough bed. A pointer indicator attached with a lateral linked-chain of the trough bed conveyor facilitates working of the two limit switches. The pointer started its journey, with the chain, at the commencement of the loading (tea leaf spreading) operation and eventually stroke the farthest limit switch to indicate and cause termination of the bed (driving motor) movement and end of loading operation of the system.