IMPROVED APPARATUS FOR COMPRESSING AND BALING LINT COTTON

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Abstract

The "Savannah Class" of baling press introduces an apparatus and method for producing a bale of lint cotton fiber by pre-compressing each consecutive charge of fiber from the lint slide to a predetermined and uniform density. The apparatus includes a supply chamber predisposed with both vertical and horizontal platens driven by independent hydraulic cylinders. The movement and cycling of the platens is such that measured charges of fibers are presented to a vertical tramping device at consistent and uniform density. The tramping device, consisting of a platen driven by two hydraulic cylinders, packs each consecutive charge into a stationary box. This process continues until the desired bale weight is reached. The tramper cylinders are driven to a predetermined pressure setting during the tramping phase of each stroke (extension) resulting in uniform compression (density). To maintain optimum density throughout the tramping phase of bale formation, the tramper stroke is varied by means of a closed loop control and infinite position sensing.

Background

For more than two hundred years the accepted method of packaging lint cotton for storage or transport at the gin has been the bale. The "bale" is the preferred form of presentation used by the textile industry as a basis for blending. At the ginning facility final packaging of lint cotton for shipment has historically been the function of the bale press. Many versions of bale presses producing various sizes and densities of cotton bales have been introduced to the ginning industry over the years. Today two preferred bale "types" dominate the global ginning industry. They are the Gin Universal Density and High Density bales.

Modern baling presses must meet design requirements to satisfy one or the other of the bale types. Domestically, that is the Universal Density Baling Press; a press capable of producing a 500 lb. bale of lint cotton 55 inches in length by 20-21 inches in width and 26-30 inches thick. Such presses use hydraulics to drive the primary and secondary axes (main compression cylinder[s] and tramper cylinder respectively) although some presses currently in operation continue to use mechanical trampers.

The purpose of the tramper in the scheme of the modern baling press is to pack lint cotton from the lint slide into the press box. Press boxes on all Universal Density Presses are approximately equal in box opening size; width from side-to-side (54 inches +/-) and front-to-back (20 inches +/-). Box length, however, can vary depending on whether the press is up-packing or down-packing, whether boxes come with retaining dogs or without, the available press tonnage (compressive) capacity and manufacturer's preference.

A significant number of modern conventional baling presses incorporate retaining dogs into their press box designs. Retaining dogs have been a necessary evil due to the natural resiliency of compressed cotton lint. In cases where conventional press boxes are short relative to tramper compressive capability and/or tramper stroke length, retaining dogs are critical to keeping lint from boiling out of the top of the press box. But they are also intrusive. Retaining dogs conflict with the uniform flow of lint cotton during the tramping process. They present a mechanical challenge in that they must (depending on design) be removed from the internal regions of the press box during certain phases of the baling cycle. The presence of retaining dogs equates to additional cost and maintenance. For these reasons elimination of retaining dogs is gaining popularity in modern press designs albeit to the detriment of additional box length, deeper foundations for up-packing presses (Figure 1), higher roof lines for down-packing presses (Figure 2), and increases in hydraulic cylinder length, both that of the ram (primary axis) and tramper (secondary axis). The effect to date of eliminating retaining dogs has been to add to the cost of material in the manufacturing process, increase the cost of installation, plus necessitates additional pump and horsepower requirements in the application process. It has been a typical "Catch – 22." Eliminate the retaining dogs to reduce cost, then add cost back due to additional materials and installation requirements.

Total connected horsepower in the modern cotton gin has increased over the years as bale per hour capacities have increased. Given the exhaustible supply of available fuels coupled with the ever increasing cost of electricity, it is in

the gin's best interest to find ways to manage energy usage. The average electrical efficiency of a modern cotton gin is typically 85%. However, unlike most other machines in the ginning system, connected horsepower at the press falls well below the 85% efficiency level.
This is because the amount of direct connected horsepower required to operate the hydraulics is usually more than the average or RMS power necessary for the press to accomplish its work (Figure 3). Also, large inductive loads such as large pump motors are notorious for having low power factors. Where pump motors are operating below full load, there is a loss in motor efficiency. It is not uncommon for hydraulic power unit designers to oversize motors and thereby build inefficiencies into the system. As a result of these "built in inefficiencies" gins pay higher demand and power factor charges. The "Savannah Class" press design addresses these factors by optimizing the total connected horsepower through a unique hydraulic and electrical control scheme.

Design Objectives

In April of 2000 Lummus conducted a worldwide market survey of several key cotton growing regions including the entire U.S. cotton belt. Among the indications gathered from the survey was that end users were looking for new technologies from the machinery manufacturers in the areas of baling presses and automation. Also, their expectations were the new technologies would provide enough value to justify the cost of investment and installation, be robust and user friendly, and would perform reliably at the lowest operating cost. From all indications this has not changed. Feed-back from the market survey has been foremost in guiding the design team as it takes on these industry challenges.

Design Objectives:

1) Develop a platform of presses having common components and features. This family of presses is to be the successor to current conventional Universal Density and High Density baling presses.
2) New design features to include short profile Press super structure to fit within current envelope in the retrofit market. For new installations the short profile feature will minimize installation costs. Include in the down-packing designs an alternate method of box removal to eliminate "special" cylinder (less cost) and reduce nuisance maintenance issues.
3) Design key components subject to high cyclical loads for "fatigue-life.".
4) Introduce new control technologies capable of processing numerous complex mathematical algorithms with minimal impact on PLC scan time. Cutting edge components include industrial PC, closed loop feedback control and real-time infinite position monitoring.
5) Interface unique patented and proven hydraulic flow control technology with load sense control and pressure compensated pump control system for maximum power efficiency within an economical hydraulic package.

Methodology

A Family of Presses:

The first step was to simplify the new product offerings. Four basic designs are on the table for the "Savannah Class" series of presses. The prototype is the Universal Density Down-packing version. The control platform for all four designs will be the same, an industrial PC linked to the real world through a TCIP BUS coupler. Non-contact/infinite position feedback devices on four of the five hydraulic axes and the press turning device simplify field wiring and provide a multitude of control opportunities. The hydraulics will be identical across the product offerings although combinations of components may vary depending upon capacities and whether the press is up-packing or down-packing. Regardless, the principal hydraulic power movers will be pressure compensated/horsepower limiting and load sensed controlled.

Short Profile Design:

Short profile designs are desirable to 1) retrofit existing installations where roof lines are low or press pits are shallow, and 2) economize on material content. Installation costs to install deep box up-packing presses are relatively high due to the foundation work associated with a deep press pit and even deeper ram pit, especially in regions where the water table is fairly shallow. A down-packing, deep box press resolves foundation issues but in turn creates others. Deep boxes require elevated platforms, longer columns, a higher battery condenser and more

often than not, a raised roof line. In either case one can expect requirements for longer hydraulic cylinders; higher pump flows due to distance (stroke) and generally speaking, more pounds of steel.
The one advantage the deep box presses have over others is the elimination of retaining dogs. This advantage is negated in the short profile design of the "Savannah Class" press.

In the down-packing version of the "Savannah Class" press the box removing cylinders have been relocated. Doing so resolves two chronic problems with previous designs; cost associated with the special box lift cylinder design and ongoing maintenance issues as a consequence of the special design. An additional benefit of relocating the box removal cylinders is it facilitates a short profile press design.

Design for Fatigue Life:
Twenty years ago the 50,000 + bale per year gin plant was the exception. It was not unusual for baling presses to stand up to cyclical wear and tear for twenty or more years. But those days are gone and presses operating in today's high volume facilities must incorporate main structural components capable of approaching, if not achieving, infinite life.

Gin baling presses are subject to significant stresses at regular intervals (cyclical loading). These stresses are inherent to the design of the respective press and the work to be accomplished. The purpose behind the design is to compress and restrain a bale of lint cotton weighing 500 pounds to a uniform density of 28 pounds per cubic foot. The maximum compressing force obtainable with the "Savannah Class" UD press is 400+ tons. Therefore at every final compression cycle the main structural members of the press are subjected to forces approaching 400+ tons. The primary affected members are typically the inside and outside axial restraining members, upper and lower sills and, to a lesser degree, the press boxes. The frequency of the stress cycles is a function of the throughput of the gin plant. The "Savannah Class" design takes into account a frequency of one cycle every 45 seconds.

To eliminate cyclical fatigue in the main axial restraining members the "Savannah Class" design introduces a pre-load to specially designed tie rods. The engineered pre-load includes a safety factor assuring the maximum force developed by the press is well below the elastic limit of the rod. Classical fatiguing of gin press tie rods is due to cyclical loading from a state of no load (or some minimal pre-load) to designed stress load, then back to the no load state. When a tie rod has the proper pre-load however, the rod will never be affected by the cyclic or changing loads during normal operation. As a result of the pre-load the tie rods used on the "Savannah Class" press, installed properly, will never be subjected to fatigue stress.

The "Savannah Class" press sills are simple plates joined at four points by specially engineered trunnions. The trunnions in turn are attached top and bottom to a compression column member and restrained by the previously mentioned tie rods. This assembly method eliminates the need for welded connections. The press sills are subjected to bending as a result of the press rams (upper sill) pushing against the lower batten assembly (lower sill) via the follower block and the lint cotton restrained within the press box. The bending of the sill plates in turn creates regional tensile and compressive stresses within the respective plates. To counter potential fatigue effect the "Savannah Class" design minimizes notch sensitivity (simple plate design), provides for pinned lateral connection at the plate's "neutral zone" by means of the trunnion connection, eliminates internal residual stresses attributed to welding and/or inappropriate geometry, and limits unit stresses to 15,000 psi or less. Pre-loading or pre-stressing was not necessary to achieve fatigue life in the case of the press sills although finite element methods were used to validate sill design parameters (Figure 4).

The stresses affecting the press boxes are the most difficult to understand. The forces on the box are not uniform nor are they constant; as the bale is compressed the lateral forces exerted on the box increase. As there was no model available to simulate a typical press box under these conditions, we chose this opportunity to measure and record the stresses in thirteen different locations on an up-packing press in Australia using strain gauges and telemetry. The data acquisition took place during the 2002 ginning season at Queensland Cotton's Dalby Gin in Dalby, Queensland, Australia. Actual measuring and recording was performed by WBM Consulting Engineers of Brisbane, QLD, Australia. In addition to the thirteen strain gauges, data from two pressure transducers (top and bottom ram pressures) and one linear position transducer (bottom ram position) were recorded. All in all over 30 million data points were recorded. The strain gauge data allowed our engineers to establish a relationship between unit stresses on the press box as a function of press ram force and/or ram position. From this a working model was developed and used in the design of the "Savannah Class" press box (Figure 5).

New Electronic and Hydraulic Control Technology:

When developing the new control concepts for the "Savannah Class" press our design team remained cognizant of the conclusions from the market survey of 2000; keep the cost of installation and maintenance at a reasonable level. However, control of the press was not sacrificed in the effort. The experienced design team had a goal of advancing the controls and hydraulics of the tramper and pusher axes to a new level of high speed operation all the while maintaining smooth accurate control. In order to accomplish our goal it was critical we have knowledge of the position of the tramper and pusher at all times. This would in turn provide for position based acceleration and deceleration. Variable position based deceleration, unlike time based systems and/or fixed position systems currently used, negates the effect of oil temperature fluctuations and is not sensitive to the presence (or lack) of cotton. In order to achieve the type of control necessary the design team chose to use magno-restrictive linear transducer technology. This technology provides accurate position feedback to within 0.03 inches.

Early in the initial design phase it was determined that in order to maintain control of the tramper and pusher axes we would need to use proportional hydraulic control valves. By combining proportional control technology with infinite position feedback we would have a true closed loop control system. As a new twist for the cotton ginning industry, our design team chose to use proportional control valves with onboard electronics and spool position feedback. The advantages of this new proportional technology are it is more reliable and simpler to install than the amplification card type system plus it allows for positive positioning of the spool under changing temperature conditions.

Once we had adequate technology implemented to easily control speed and position of the tramper and pusher axes under changing load and temperature conditions, we needed to come up with a simple method for controlling the oil flow to the axes that would also meet any and all capacity requirements. When using proportional valves, improper control of the oil flow most often results in unnecessary build up of heat. One way to overcome such a situation is to use inexpensive vane pumps and "dump" them when not in use. This is typical of current hydraulic systems in modern high production gin plants. Under this method one just dumps the portion of the oil not in use over a relief valve at the end of the cylinder stroke. Another method is to use pressure compensated pumps which will reduce oil flow but not until the pressure drop across the flow valve reaches compensator setting. A new approach our design team is offering is the use of load sensing to maintain a set pressure drop across an orifice. In the case of the "Savannah Class" press, the orifice is the flow control valve for the particular axis to be controlled. In order to fully utilize this technology we had to invest in variable displacement pumps. Our choice was to go with variable displacement pressure compensated piston pumps. Although relatively expensive when compared to vane or gear pumps, the versatility of the piston pump resulted in horsepower reduction and eliminated the need for redundant fixed displacement pumps.

As mentioned earlier, part of the justification for the higher cost pump came through reduced horsepower requirements. A significant portion of the design time was spent modeling the hydraulics to produce the necessary forces and speeds with lower connected horsepower than that supplied with previous or even current baling presses. A program had to be written that would model the speed of a press with given connected flow and horsepower. Results of the model analysis led us to believe we could get by with significantly less horsepower and flow thus offsetting the initial high cost of the piston pumps.

There remained one final issue to be resolved regarding our new control scheme. How were we going to control the horsepower of the pumps to obtain the higher efficiencies? The first logical choice was to use a horsepower control that can be purchased off the shelf along with the pump. This type of control is in fact currently used on some gin manufacturers presses but it does have some disadvantages. The control is a mechanical setting and cannot be changed during operation. Therefore once the horsepower level of a pump is set it is constant until manually readjusted. This standard off the shelf control would not meet our requirements. Instead our design team in collaboration with engineers from Bosch/Rexroth Industrial Hydraulics opted to control the horsepower using the previously mentioned load sense control. Given we had pressure feedback of both the tramper and press axes and we had the ability to control flow using load sense pump controls in conjunction with proportional control valves, the horsepower controller became a mere series of mathematical calculations within the press program. The end result of this unique control scheme is the ability to vary the power requirements of each axis as needed while at the same time optimize the available horsepower.

Design Phases I through IV

Phase I of Design (April 2004):

After two years of brainstorming, serious design work started on the "Savannah Class" press in August of 2003. The first task was to find a partner gin to install the press, fully realizing that the first unit was a prototype subject to operational issues and changes along the way. Fortunately that partner materialized in Kent Fountain, President and CEO of Southeastern Gin located just an hour and a half from Savannah in Surrency, GA. Given the design work didn't commence until August of 2003 there was no opportunity to install and operate the press during the 2003 harvest season. Kent agreed to hold back 30 modules of cotton at years end for us to use during the Phase I tests. Installation of the press commenced soon after the conclusion of the 2003 season. Testing of the press took place during the month of April 2004. Although the test run consisted of approximately 300 bales, the premise behind the variable stroke tramper and short box profile were validated (Figure 6). Some issues related to tramper and bed structure, box lift design and overall electronic control concept emerged as areas for reconsideration. During the Phase I testing cotton moisture averaged in the 5% range. The largest bale produced weighed 617 lbs. Even so, cotton never emerged above the top of the box during the press turn cycle.

Phase II of Design (July 2004):

Our design team reconvened after the initial prototype run was completed and prepared a punch list of issues for reconsideration. Their focus was on the following areas;

1. tramper sill design
2. press bed and bed lift design
3. box lift methodology
4. box lift guides
5. press control platform

The "Savannah Class" tramper is capable of developing up to 60 tons of compressive force. Additional consideration was to be given to the impact of forces four times the normal over such a long axis. Due to lack of time not all structures impacted could be redesigned prior to Phase III. This remains to be addressed during Phase IV. Similar issues involved the press bed weldment and bed lift structure. These were addressed during Phase II and validated during Phase III.

The box lift concept of two dedicated box lift cylinders per box worked to perfection but failed in the end. The failure was due to the complexity of plumbing four cylinders mounted to rotating boxes. It was both impractical and expensive. The alternate solution turned out to be a proven configuration whereby two cylinders are mounted within the bottom press sill. The double acting cylinders remove the box from the compressed bale by extending the cylinder rod through holes in the press bed and pushing against the bottom of the press box. Thus our original intent of pushing the box off of the bale rather than pulling remains a feature of the press.

Reconfiguration of the box lift method required a redesign of the box guide system. The Phase I design relied on the cylinders being attached to the bed at the head end and the box at the rod end. This arrangement along with simple Micarta guide pads was all that was required to hold the boxes down and guide them during the lifting process. The new lift configuration necessitated addition of guide tracks on both sides of the center main column structure and on the press end column. Also, guide cam rollers were added to each box along with box hold-down latches. After running the entire 2004 harvest season only a few minor modifications are required to complete the lift and guide system for Phase IV.

One of the most radical changes made during Phase II was to the electrical control system. The Phase I control was to be a conventional PLC with touch screen interface (OIT). The decision was made to go with the Group Schneider Modicon for the PLC and a Magellis OIT. It was immediately obvious during the initial stages of the Phase I test run this equipment would not support optimization of the "Savannah Class" press. Algorithms for load sense control and bale weight position slowed down the PLC scan time to an unacceptable level. This resulted in erratic operation and frequent faults. Process optimization was not an option during the Phase I test run nor would it be in the future as long as an industrial PLC was to be the operating platform. The solution came in the form of an industrial PC. Due to compressed time constraints our design team enlisted the help of Livingston and Haven's

Industrial controls team to come up with a solid PC based control that could perform complicated math calculations without degrading scan time.

Our partner chose a dynics PC linked to Beckoff branded I/O via a TCP communication module. The I/O is capable of 2 msec. read/write time. After installing the PC and writing most of the program we found that 6 msec. was the optimal total scan time to use. Of the 6 msec. the total time the PC uses to process the actual press control program is about 7 μsec. Together we chose to use Visual Logic Controller (VLC) formerly known as Steeple Chase as the control software for the press. With this software we are not limited in the number or complexity of mathematical computations critical to the control and optimization of the "Savannah Class" press. The VLC software allows one to store large amounts of data in the program and in data-bases on the PC itself. By continually retrieving and up-dating the various data bases the "Savannah Class" press in effect "teaches" itself to respond to certain operational parameters based on an operator's process variable (operator's input). This self-tuning process is the foundation of bale weight and position control. In addition to the software, the design team chose Iconics as the graphics package to interface VLC with the user. Through Iconics we are able to present the user with a diagnostics tool second to none. The graphics mimics all the possible scenarios the operator could be confronted with during the operation phases of the press. The new interface also provides administrative tools such as password protection allowing for trouble shooting modes that can only be accessed by authorized personnel.

Southeastern Gin held over a few partial modules from the Phase I testing to use during the test portion of Phase II. These bales were run during late July 2004. With few exceptions the redesign was successful. It would take a complete season of running to validate the design to the satisfaction of all parties involved.

Phase III of Design (Fall Season 2004):

Harvest for the 2004 season started in late September and ginning soon thereafter. Southeastern Gin processed 36,000+ bales during the season. The only significant issues to be revisited were the original structural considerations remaining from the Phase I tests, box and bed latch and the rotator design. Redesign of these areas of concern has been underway since mid-November (Figure 7). Two other issues to be put in the "opportunity for optimization" category are bale weight and moisture measurement. Consistency of bale weight control was an issue periodically during Phase III. It was determined electrical noise was a major contributor to the problem. This can be marginalized through proper installation procedures. Near the end of the season the bale weights were more consistent as the programmer progressed further along the learning curve towards optimization. The beauty of the flow logic determining bale weight is that the controller tunes itself narrowing in on a nominal bale weight based on an operator's set point. It is anticipated bale moisture measurement will further tune bale weight although this aspect of the controller logic has not been fully tested. Work in this area will carry on into Phase IV.

During the final weeks of gin operation our controls team took the opportunity to log and record true RMS press power at Southeastern Gin. An AMPROBE® DM-II™PRO data logger/recorder was used to record true power consumption over a several bale run. At the time the gin throughput was averaging 33.6 bales per hour. The data collected proved our design team was on the right track. True RMS power averaged 40.3 kW or 54.4 horsepower over the duration of the run (Figures 8 and 9). With this preliminary data and anticipated future acquired data we are confident the "Savannah Class" press will comfortably perform at 45 to 50 bales per hour with 100 connected horsepower at the hydraulic power unit.

Phase IV of Design (Production Version for 2005):

The major design effort for the fourth and final phase of the "Savannah Class" project has already started. Albeit changes to the design were made throughout the project, the performance to date plus the minimal work to be done to bring the prototype press up to that of a production level is proof of a well executed team effort by all participants under trying circumstances and a compressed time schedule. Optimization will continue in the areas of power consumption, various control schemes and hydraulic technologies all geared toward creating a unique user friendly and versatile family of value added baling presses for the cotton ginning industry.

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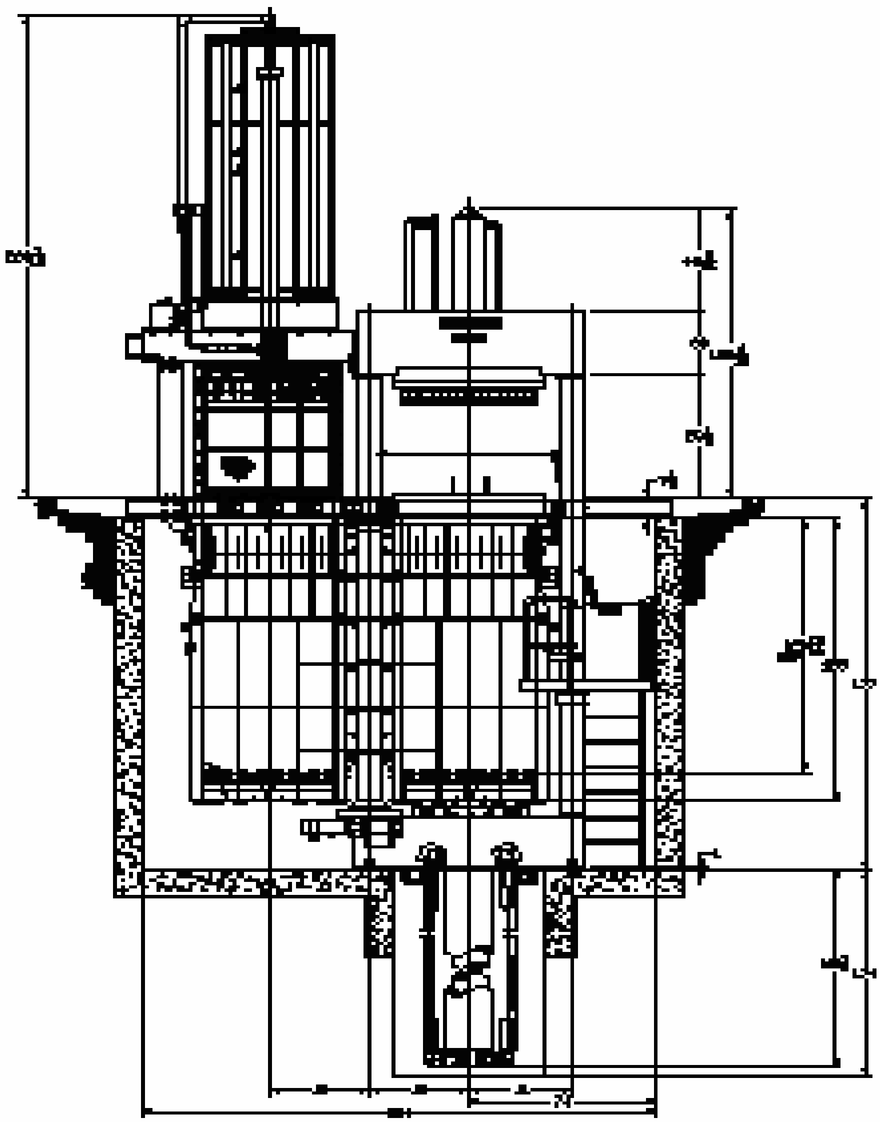
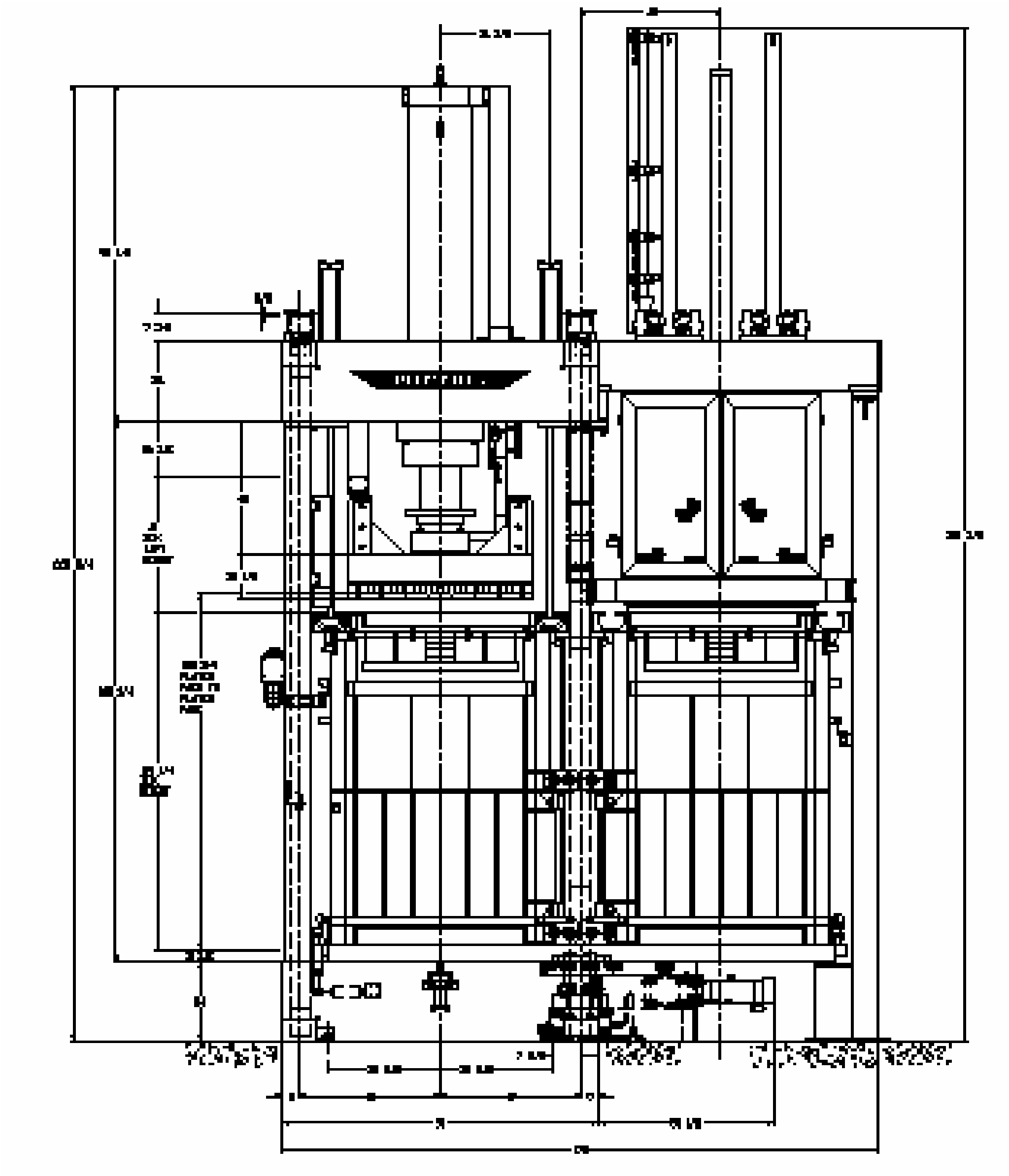


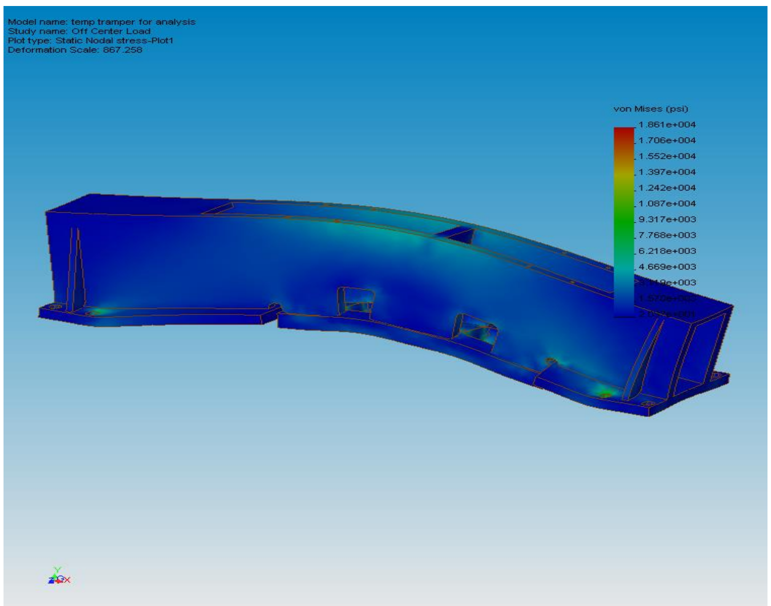
Up Packing Dor-Les® 20 x 54 U.D. Press
Figure 1



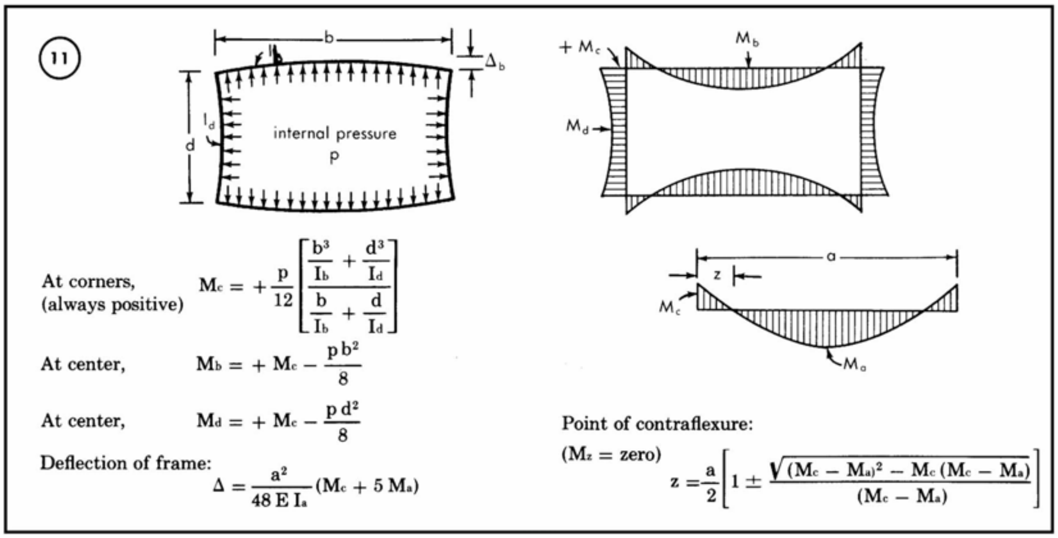
Down Packing Lift-Box® 20 x 54 U.D. Press
Figure 2

$$\text{RMS HP} = \sqrt{\frac{HP_1^2 \times t_1 + HP_2^2 \times t_2 + HP_3^2 \times t_3 + HP_4^2 \times t_4 + \ldots\ HP_x^2 \times t_x}{t_1 + t_2 + t_3 + t_4 + \cdots\ t_x}}$$

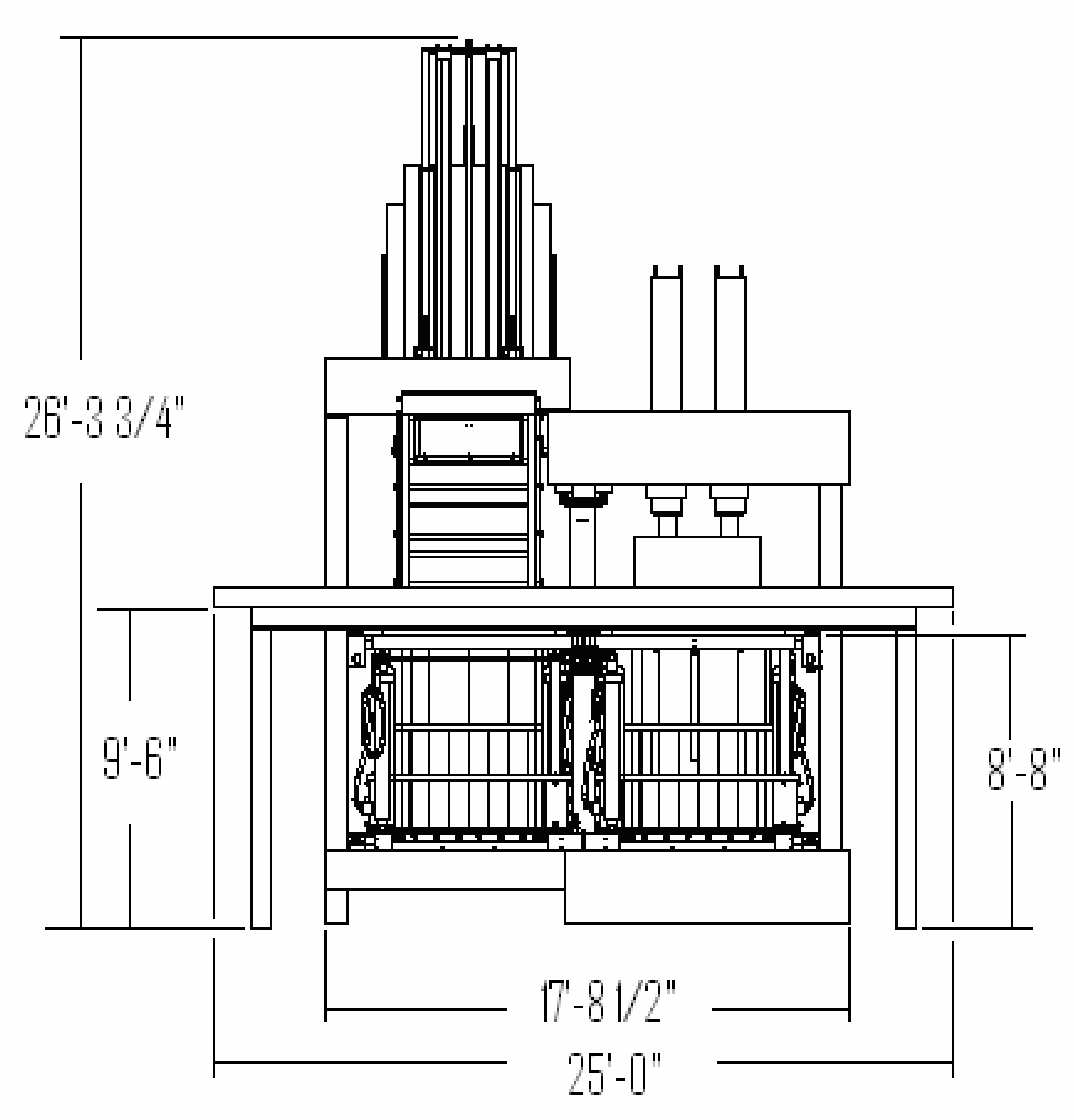
Formula for calculating RMS loading for one time cycle.
Figure 3



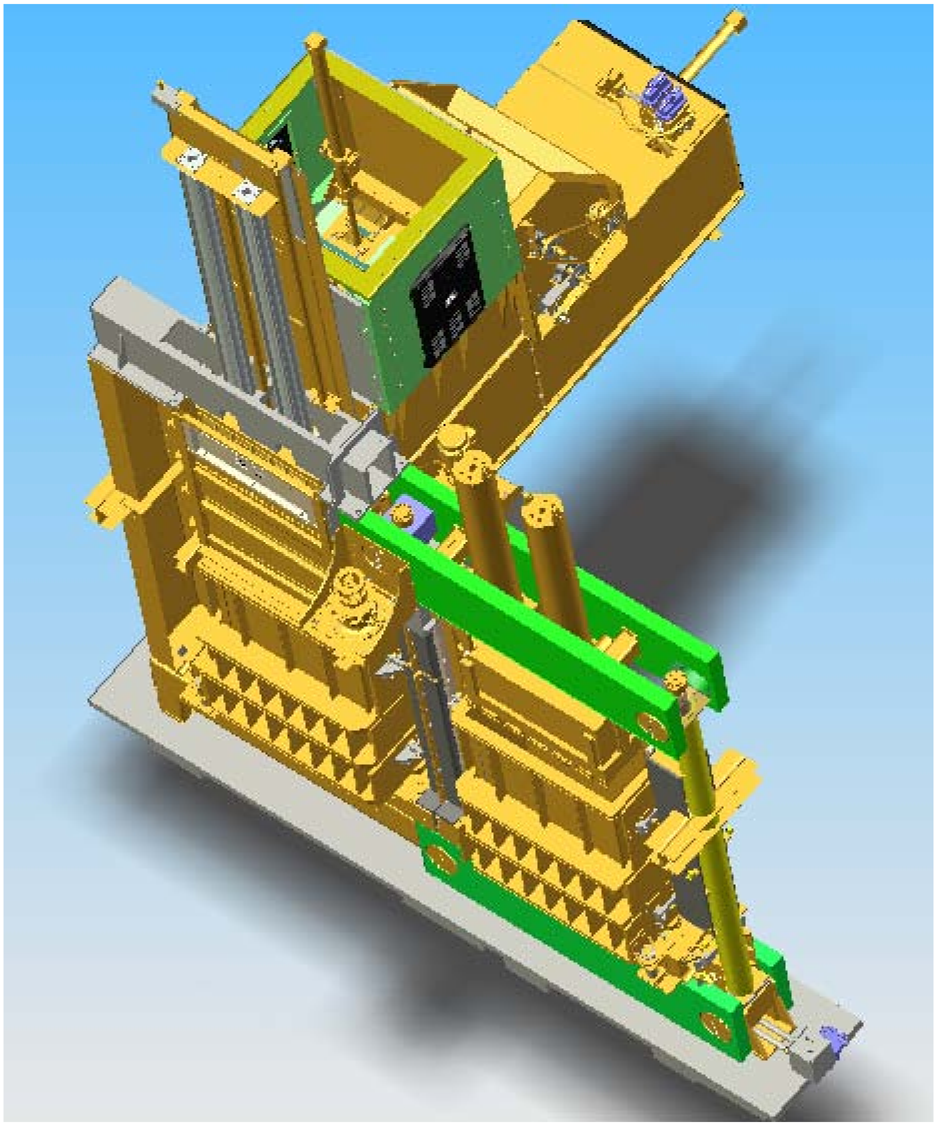
Von Mises stresses validated using Cosmos FEA
Figure 4



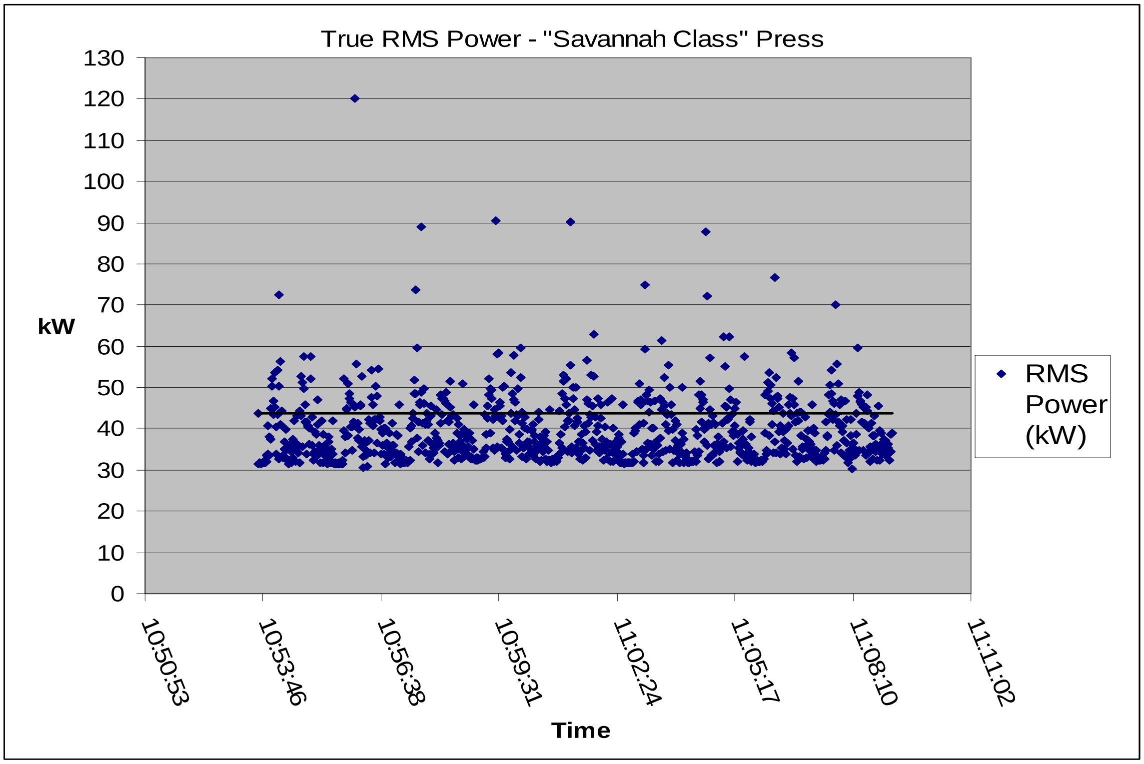
"Zero Moment" Determination for Press Boxes (Mathcad Pro)
Figure 5



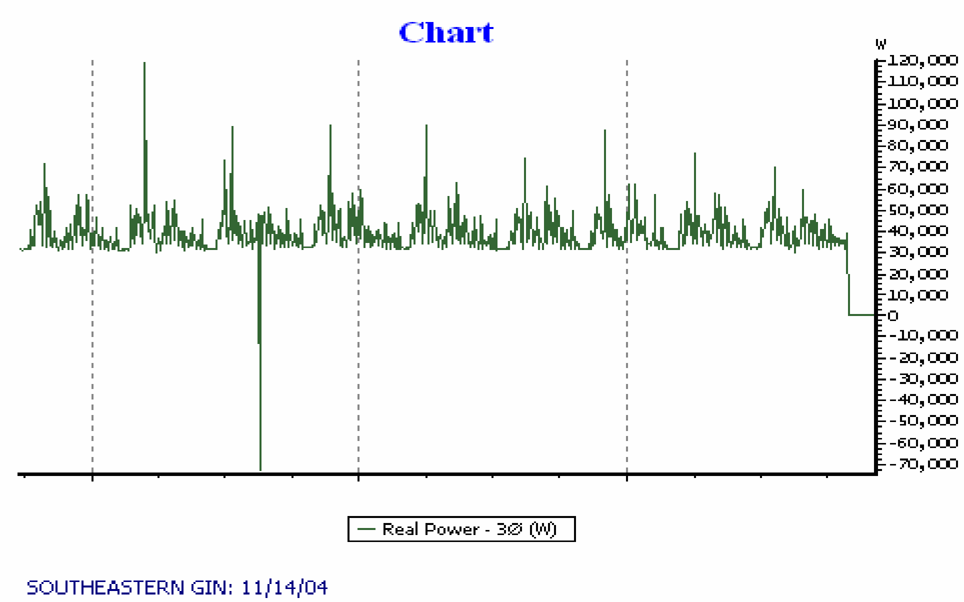
Phase I "Savannah Class" 20 x 54 Down Packing U.D. Press. Note 4 Independent Box Lift Cylinders.
Figure 6



Final Phase of “Savannah Class” 20 x 54 Down Packing U.D. Press
Figure 7



True RMS Power – kW vs. Time (33.6 BPH)
Figure 8



AMPROBE® Chart of True RMS
Figure 9