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FINAL REPORT - SRDC PROJECT BSS251
COMMERCIALISATION OF LIGHTWEIGHT ELEVATOR AND ADVANCED SECONDARY CLEANING SYSTEM FOR SUGARCANE HARVESTERS

by

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SUMMARY

The Australian sugar industry is facing the challenge of increasing extraneous matter (EM), depression of ccs, sugar quality issues, and increasing harvesting and transport costs per tonne of final product. In addition, cane loss remains a major background issue. Leslie and Wilson (1996) identified EM as a major contributor to the depression of ccs in the northern canegrowing regions. If low EM is seen as paramount by the industry, either cleaning the cane at the mill in dedicated cleaning plants, or improved performance of cleaning systems on harvesters, is required.

Improving the performance of harvester cleaning systems is not easy because a number of fundamental problems exist. Rational review of the function of trash removal from a stream of billets and trash, particularly under wet trash conditions, indicates that effective cleaning is extremely difficult to achieve in one pass through any cleaning system. This is due to the interactions between the leaf material and billets of cane.

The goal of this project was to develop a pre-production prototype lightweight harvester elevator and integrated secondary cleaning system. The project was commercially driven and built on the knowledge gained from the SRDC-funded project BSS210 in which high-speed conveyor technology and advanced pneumatic cleaning concepts were integrated into a cane harvester. The design criteria targeted enhanced machine performance through reduced cane loss and EM, whilst reducing machine weight and improving machine stability.

The concept of high-speed hugger belts and a blower cleaning arrangement tested in BSS210 was found to dramatically outperform current secondary extractor systems. The pre-production prototype was designed as both a retrofit item and for fitting to new machines. This facilitates a more rapid adoption over systems that are available only on new machines.

Major operational and reliability problems were encountered in the testing of the proof of concept prototype system. The major difficulty encountered included the poor operational reliability of the hugger belt configuration. In addition, improved feeding and prevention of foreign material buildup were other issues to be addressed in future designs.

Modifications to alleviate these problems were developed and incorporated in the proof of concept prototype. Further field testing was completed to demonstrate that these modifications overcame the above problems. Design criteria were developed and a pre-production prototype was designed and fabricated at BSES Bundaberg. Field testing of the prototype unit was undertaken to demonstrate the mechanical and functional reliability of the redesigned system.

The difficulties experienced with the performance of the proof of concept prototype were successfully addressed and this has resulted in the development of a commercially viable pre-production prototype.

The project did not achieve all its objectives due to several reasons. The number of field trials and operating hours achieved were very low, resulting from a combination of the early end to the 2001 season and harvester mechanical problems. These problems resulted in the test program not effectively quantifying the EM and cane loss characteristics of the pre-production prototype system.

In addition, due to the limited testing undertaken, the mechanical and functional reliability could not be rigorously evaluated. It was therefore deemed premature to undertake a full finite element analysis of the structure because the design may have required further modifications.

The project, however, has in no way been unsuccessful. The project has very significantly progressed knowledge relating to the cleaning of cane, and has clearly shown that the concepts embodied in the pre-production prototype have considerable potential.

Key outcomes of the project included:

- the development of an alternative design of the harvester elevator bowl, which potentially enhances the performance the current primary extractor;

- the ability to feed billets into a hugger belt system at commercially viable rates has been demonstrated;

- the ability of a hugger belt system to present billets in a configuration more suitable for effective cleaning than the current chain and slat elevator has been demonstrated;

- the enhanced airflow characteristics and cleaning performance offered by the blower type secondary cleaning module have been graphically demonstrated;

- the lighter weight and increased stability due to the reduced overturning moment of the elevator assembly have been demonstrated via positive comments from machine operators.

This project was a collaborative venture between a primary research organisation (BSES) and manufacturers of equipment for the sugar industry (CNH Austoft and Gough Plastics). The project has demonstrated a significant degree of collaboration between these parties, in a shared goal of producing improved machine performance to better meet the needs of the Australian sugar industry.

Further commercial evaluation of the pre-production prototype will be undertaken during the 2002 season by BSES. This would allow the industry to capture the significant developments made throughout this project, and allow the commercial development and availability of a high-speed elevator and advanced cleaning system.

1.0 BACKGROUND

High levels of extraneous matter (EM) in cane are known to reduce ccs of the cane supply, at a cost to growers. High EM is also a cost to millers through low bin weights (and increased cost of transport) and reduced cane crushing rate. While some mills are capable of using additional EM for electricity co-generation this does not necessarily offset the above costs.

The reduction of EM in the cane supply is an increased priority for the industry as it aims to maximise sugar quality whilst minimising sugar production costs.

Cane and sugar loss during harvesting has a direct effect on whole of industry returns. In addition, high loss of sugar during harvesting is a potential environmental issue when the material enters waterways following heavy rainfall.

Cane loss and EM levels must be reduced to more acceptable levels to enable the industry to meet sugar quality targets and minimise sugar loss during harvesting.

A significant increase in harvester pour rates has been witnessed throughout the Australian sugar industry in recent years, even where harvest contract sizes have not increased. This increase in pour rate has been primarily facilitated by an increase in harvester engine power. Increases in harvester pour rates are, however, essential for the continuing viability of the cane harvesting sector, and subsequently the industry. Unfortunately, the inability of current harvester designs to effectively clean the cane at these pour rates, whilst maintaining acceptable cane loss, has been clearly demonstrated from trials in north Queensland (Whiteing *et al.*, 2001). The increase in EM in the cane supply resulting from higher pour rates has been identified as a primary cause of the low ccs problem in north Queensland (Leslie and Wilson, 1996).

Numerous workshops have targeted this increasing EM problem, with a wide range of solutions being canvassed. The fundamental problem is the inability of the current harvester cleaning system design to achieve both high extraneous matter removal and low cane loss at the high pour rates the industry now demands.

Sugar balance research undertaken by BSES and Mulgrave mill, showed that trash removal levels achieved by harvesters ranged from over 80 per cent under good conditions to around 30 per cent under adverse harvesting conditions. Replicated trials by Whiteing (2002) have shown that pour rate and harvesting conditions are the primary determinants of final EM levels with current harvesters.

Research by Davis and Norris (2000) has demonstrated that in lodged green cane, instantaneous pour rates of modern harvesters vary from near zero to over 400 t/hr in an erratic cyclic pattern. Similar, patterns occur when harvesting erect green cane, although are less extreme. Observations from BSS165 and BSS189 confirm a strong relationship between adverse harvester feeding and poor cleaning system performance.

Without a major redesign of harvester feeding systems or the adoption of an alternative system to buffer this extreme mass-flow variability, primary cleaning systems have to operate with this erratically varying throughput. This variability in feed severely compromises the performance of any cleaning system, irrespective of the sophistication of the design. Thus, while several research projects have targeted enhanced primary cleaning systems as a potential method to eliminate the need for the secondary extractor, giving both improved cleaning through the design of the cleaning system and reduced elevator weight, by the removal of the secondary extractor, progress has been limited.

Clearly, alternative approaches have to be found if significant gains are to be made in cleaning on the harvester. Two issues dominate the potential for effective cleaning on the harvester, including:

- interaction of trash and billets during the separation process;
- instantaneous material flow rates through the cleaning station.

A well defined problem with the removal of large proportions of trash in one pass cleaning systems is the interaction between the trash and billets. This typically results in the wrapping of trash around billets and exacerbates at higher pour rates (Quick, 1982), or as the trash becomes damp. This results in a dramatic reduction in cleaning performance and is demonstrated when current cleaning systems are operating under wet harvesting conditions (Hobson, P., pers. com.).

The concept of dual-pass cleaning, therefore, had inherent logic, because the mixing and agitation of the billets, as they are transferred between cleaning stages, both loosens the attachment between leaf material and the billets (particularly important under wet harvesting conditions) and re-orientates the material for the secondary cleaning. In a well designed cleaning system, maximum use is made of the differences in aerodynamic and mechanical properties between trash and billets. This is to achieve separation of cane and trash during these transfer phases, thus presenting the cane and trash in a configuration to maximise cleaning efficiency. Similarly, the MF405 prototype utilised the inherent characteristic of billets to settle to the bottom of a chain and slat elevator to concentrate the trash at the top of the material profile where it could be more easily removed. This, along with a quite different slat design to current elevators, which enhanced evenness of feed, allowed this machine to achieve substantially lower EM levels than machines of the CNH Austoft 7000/7700 and Cameco 2500 designs, where the trash is predominantly concentrated at the bottom of the material profile entering the cleaning chamber.

The inadequacies in the conceptual design of current cleaning systems for high pour rate cleaning are exacerbated by inappropriate presentation of the cane to the cleaning chamber directly from the choppers (Hobson, 1995; Quick, 1982).

In the Brazilian/Colombian cane cleaning plants, maximum use of this effect is achieved by letting billets and trash settle on high-speed belts before they are presented to cleaning modules incorporating air-curtains blowing from below the cane mat. Because the trash has concentrated towards the top of the material profile, maximum trash removal can be achieved by this upward airflow with minimum opportunity for cane loss by billets being entrapped in trash.

Another advantage of multi-pass cleaning or, more particularly secondary cleaning on a cane harvester, is that the variability in the material flow rate is reduced after conveying by an elevator. Utilising this opportunity to optimise material presentation, an effective secondary cleaning system can be developed.

Despite nominally capitalising on some of the fundamental advantages of a secondary cleaning system, trials undertaken in BSS189 indicate that trash removal efficiency of current secondary extractor systems is in the order of 10-20 per cent. Clearly, problems exist in the current extractor design and the characteristic pulsing presentation of cane to the secondary extractor by the current chain and slat conveyor. Whilst somewhat better than the presentation to the primary extractor, the presentation to the secondary extractor is still highly inappropriate for effective cleaning to occur. This inappropriate presentation, along with a range of design constraints, leads to relatively low cleaning efficiencies and excessive cane loss under conditions where there is high vegetative EM in the material being presented.

The concept of presenting material in a thin mat at high-speed to a transverse high-speed air-curtain has a number of fundamental advantages. The thin mat minimises the potential for interactions to occur between the cane and trash, and the momentum effect of the billets travelling at high-speed allows high transverse air velocities to be used without fear of excessive cane loss.

Considerable resources have been committed by SRDC to projects addressing more appropriate cleaning chamber designs and alternative cleaning system concepts. To achieve the full potential offered by any of these advanced concepts, a major redesign of the harvester is necessary and, as such, this is a medium to long-term development. Significant effort is, however, being expended to manipulate the concepts within the constraints of the current harvester layout. The presentation of material to these systems (directly from the choppers) is such that the potential of the concepts is unlikely to be fully realised. If, however, more space was available at the rear of the harvester, better designs exploiting more of the potential performance gains of these concepts would be possible.

In addition to the issues of cleaning and cane loss, machine weight and stability are also crucial issues. Whilst best engineering practice is currently used by the manufacturers to minimise elevator mass, its mass and the mass of the secondary extractor not only add to machine weight, but also adversely impact on machine stability when operating across slopes. Previous attempts to redesign the elevator from non-ferrous metals to reduce weight have introduced seemingly insurmountable problems with wear, electrolysis/ corrosion, durability and cost.

Research undertaken by Austoft in 1994/95 on reducing harvester weight found a major constraint was the weight of the elevator. Its weight and weight distribution dictated the required strength and weight of the harvester, if acceptable stability and durability were to be achieved. A conclusion from the research was that if a lighter weight elevator with reduced overturning moment was achievable, then significant further weight reductions in other components of the harvester would be possible (Williams, J. pers. com.).

This project, therefore, arose from the identified need by industry to develop a lightweight elevator with enhanced cane cleaning performance. This issue was addressed in BSS210, with the development of the proof of concept, lightweight high-speed elevator and advanced secondary cleaning system (Norris and Davis, 2001). Although unexpected problems occurred in the design of the high-speed hugger belt system, the proof of concept system clearly demonstrated the potential of the concept. Trials demonstrated:

- high levels of trash removal under a wide range of conditions. Whilst a general reduction in cleaning efficiency occurred as pour rate increased, trash removal efficiencies were typically high, eg 60-70 per cent at 55 t/hr versus 50-60 per cent at 120-130 t/hr. At a given pour rate, the cleaning efficiency was relatively constant despite significant changes in the composition of material entering the cleaning chamber;

- low cane loss. Typically cane loss was below 1.5 per cent over a wide range of operating conditions, including high pour rates and high trash conditions;

- reduced weight and overturning moment. The secondary cleaning system weighed 150 kg versus 285 kg for a standard secondary extractor. Reducing the overturning moment by 30 per cent.

By comparison, using the same testing procedures (feeding the harvester with pre-cut cane at a controlled feed rate), Ridge and Dick (1987) tested a then current model production harvester. The results of these trials demonstrated that at a pour rate of 60 t/hr the primary extractor system removed 92 per cent of the trash with a corresponding cane loss of 15.6 per cent. Whilst significant developments have been made in primary cleaning systems since these trials (increase in extractor diameter and variable speed fan), these and other trials have demonstrated a good correlation between workshop testing and field testing.

Further development of this prototype elevator system has the potential to deliver a number of significant advantages including:

- a reduction in weight and overturning moment of the harvester. This increased stability and the reduction in elevator weight would allow subsequent weight reduction in other harvester components;

- potential to increase the dimensions available for the cleaning chamber, and the potential to move the elevator further to the rear, allowing incorporation of further equipment in the primary cleaning area;

- improved performance of the proposed secondary cleaning system. This would allow the current primary extractor systems to operate in a mode consistent with lower cane loss;

- retrofit to current harvesters.

Other issues to be addressed relate to the operational reliability of the hugger belt configuration. Initial trials of the final prototype in the workshop indicated major problems, with the belts requiring continual adjustment of belt alignment. A solution to this problem would allow the industry to capture the significant developments made throughout this project, and allow the commercial development and availability of a high-speed elevator and advanced cleaning system.

2.0 OBJECTIVES

This project aimed to develop and test, to commercial prototype stage, a new concept of cane harvester elevator and integrated secondary cleaning system. The proposed design offers:

- a cost-effective retrofit elevator, which will significantly enhance the product quality and reduce cane loss from current harvesters;

- an elevator system for new harvesters, which complements the performance of alternative cleaning system designs being developed.

The design will be based on the proof of concept system developed in BSS210, which demonstrated lower weight, dramatically improved cleaning performance and, through enhanced aerodynamics of the elevator bowl, the potential to enhance the performance of current and proposed harvester primary cleaning system.

The key objectives of the project included:

- design and manufacture of a new prototype on the basis of knowledge gained from the BSS210 prototype;

- undertaking extensive testing of the prototype both in the workshop and in the field to characterise performance and ensure mechanical and functional reliability of the redesigned system;

- undertaking final design to include full finite element analysis of the frame to ensure structural integrity and functional reliability, and incorporating appropriate features for ease of manufacture;

- manufacturing the pre-production prototype and undertaking a rigorous field testing program.

The project will again be conducted in conjunction with key commercial stakeholders, including Gough Plastics and CNH Austoft.

3.0 DESIGN DEVELOPMENT

A number of operational issues were identified with the proof of concept prototype developed in BSS210. These included belt tracking and feeding of billeted cane into the hugger belts. The solution pathway to these issues involved developing design modifications and refinements to the overall system. It was decided that the most appropriate approach in developing these refinements would be to undertake modifications to the existing proof of concept prototype. This would build on the knowledge base before the design criteria were finalised and the development of the next prototype was undertaken.

The design modifications incorporated on the proof of concept prototype and the criteria developed for the next prototype will now be discussed in terms of layout development.

3.1 Belt tracking

The major issue to be resolved to facilitate the further development of the concept of the high-speed belt elevator was to achieve reliable tracking of belts. Discussions with Beltreco, a company with experience in materials handling and a consultant on BSS210, were held to explore solutions to the belt tracking problems. Beltreco provided limited advice and recommended further consultation with other companies with experience in materials handling involving asymmetrical loading of belt conveyors, especially woodchip and grains.

The consultation process identified a number of areas that would inhibit stable belt tracking. These included the following.

- Frame misalignment. The main structural frame of the proof of concept system had not been manufactured square and the head and tail rollers could not be set up to be parallel. Minor modifications to the frame allowed the misalignment to be reduced; however, the problem could not be totally alleviated without major corrective surgery. This is a fundamental criterion that could be fully addressed in the design and manufacture of the next prototype.

- Buildup of foreign material behind the belts. The buildup of trash and other material around the tail rollers of each of the belts (and subsequent buildup on the tail rollers) altered the surface properties under the sides of the belts. The hypothesis, which best explained the characteristics of the problem, was that small changes in the coefficient of friction between the belts and the low friction backing plate (caused by moisture, dirt) caused instability in belt tracking. This was reduced by ducting air from the secondary cleaning system to blow loose trash and dust away from the belts.

- Idler roller location. The idler rollers in both belts were relocated on the basis of minimising adverse impacts of misalignments if dirt buildup occurred on the rollers. This reduced the problem and was an important consideration in the design criteria.

- Roller crown. Initially the crown on the rollers was set at approximately 2 per cent of the diameter. That is, the diameter in the centre of the roller is approximately 3 mm larger than the 152 mm diameter of the outer edges. Further advice indicated that a crown of approximately twice the initial magnitude was more desirable. Key rollers were modified with a more aggressive crown. This additional crowning had limited impact by itself.

The above recommendations were incorporated into the proof of concept system. The results of the review also indicated that, with the asymmetric loadings anticipated, it would be difficult to achieve an adequate degree of belt tracking control totally by these modifications. During the review process any alternative belt tracking technologies of potential use were identified and researched. These included the concept of self-steering rollers which track and guide the belt immediately the belt begins to track off-line. The self-steering roller has an internal pivot that is perpendicular to the plane of the belts. As the belt moves off-centre it contacts the tapered outer edge on that side of the belt, which forces the roller to pivot on its centre pivot. Since the roller in no longer perpendicular to the direction of belt travel, the roller immediately steers the belt back to its central position. An off-the-shelf self-steering roller was obtained and incorporated into the proof of concept prototype elevator.

After completion of the above modifications, static trials were undertaken. These proved highly successful enabling the proof of concept system to undergo further field tests at the end of the 2000 crushing season.

3.2 Elevator bowl

The proof of concept elevator bowl is a major departure from current designs. It rotates only in a horizontal plane via the slewing mechanism of a standard turntable. The vertical movement of the elevator is achieved by rotation about a secondary horizontal pivot at the junction of the bowl and the elevator. This design allows the substantial lowering of the bowl and efficient utilisation of the area around the rear of the machine. The design increases the flexibility with the length, width and depth available for the primary cleaning system.

The proof of concept system used a belt conveyor as the base of the elevator bowl. Feeding the cane from the near horizontal belt conveyor into the steeply inclined hugger belts involved the use of an intermediate roller system. Similarly, the lack of aggression of the belt meant that achieving reliable feed of billets from the full elevator bowl at startup was difficult at the high pour rates required.

A new design was conceptualised for the base of the elevator bowl, based on a chain and slat elevator system. This offered a number of advantages including:

- the chain and slat system can follow a curved path, rather than the simple flat floor as with belt elevator. This allows:

  - better utilisation of the available space;
  - the transition angle from the bowl into the hugger belts to be minimised;
  - an increase in aggressiveness of feed.

- the feed control system can also be more aggressive because the slats are more robust.

The chain and slat conveyor was designed and components sourced. In addition, a new dedicated bowl arrangement had to be designed to incorporate the chain and slat conveyor.

A standard turntable was acquired and modified to allow mounting of the bowl arrangement. The bowl arrangement was fabricated from 5 mm plate with suitable gussets for stiffeners. The existing hugger belt unit mounted directly on to the new bowl and pivoted at the rear.

The chain and slat conveyor was constructed using four standard 12-tooth sprockets matched to the two 80-link lengths of 38.3 mm pitch chain. The slats were fabricated from 75 mm sections of 165 mm OD pipe and therefore are concave in shape. The concave geometry of the slats allowed the conveyor to characterise a smooth curve whilst moving around the sprocket at the delivery end. This minimises the gap and prevents billets and foreign material catching between the slats. The conveyor and bowl were fabricated at BSES Bundaberg.

The bowl was increased in volume with sides made more open using larger diameter perforated mesh. This was to further increase the performance of the primary extractor via improved airflow.

3.2.1 Material flow control

Bridging of material and difficulty in controlling feed of the material into the hugger belts are issues critical to the successful performance of the hugger belts. The fundamental criterion is to effect aggressive, continuous feeding whilst presenting the material in a relatively thin layer. A number of concepts were tested in the proof of concept bowl and belt conveyor design, with limited success. The chain and slat conveyor allows a more aggressive feed system to be implemented and alternative concepts were developed and incorporated into the new bowl arrangement.

Two rollers were positioned in the transition zone to control and maintain aggressive feeding to the hugger belts. Firstly a 'scalper' roller was positioned close to the entry point, consisting of two flaps offset by 180 degrees and set up to rotate against the direction of material flow. The aim of this roller was to control the depth of material to the transition zone and the hugger belts. Forward of the scalper roller and immediately prior to the entry with the hugger belts is the feed roller. This spiral wrapped roller was designed to spread the material evenly to allow even distribution on to the belts and to prevent bridging of material. The roller applied tension to the material at all depths by way of shock absorber. Figures 1 and 2 illustrate the chain and slat conveyor and transition zone with roller feed system.

Figure 1: Chain and slat conveyor and spiral wrapped feed roller arrangement.

Figure 2: Transition zone of chain and slat conveyor and scalper feed roller arrangement.

No modifications were made to the secondary cleaning system and it remained as developed in BSS210. The design specifications can be found in the BSS210 final report by Norris and Davis (2001). The proof of concept hugger belt and secondary cleaning systems were fitted to the new bowl arrangement. The complete unit was then fitted on to a harvester ready for testing.

3.3 Proof of concept prototype: design testing and refinement

3.3.1 Field trials

Initial field trials of the modified proof of concept system were conducted at the BSES research station in Bundaberg. These initial trials were to evaluate the belt tracking system and pour rate capability before more extensive field testing was undertaken. Approximately 60 tonnes of material were harvested. The belt tracking system was found to be inadequate in maintaining active guidance of the belts due to a slow response time. On further investigation it was found that a very small activation force was required to effectively steer the belt via the self-steering roller. This led to the design of a simple feedback system incorporating nylon rollers with a groove that runs on the side of the belt with a flexible link to the self-steering roller. This simple tactile system gave adequate belt position control to allow further field testing to be undertaken. The maximum achievable pour rate was 100 t/hr and was limited by the difficulty in maintaining reliable feed from the elevator bowl into the hugger belts.

Further field testing was undertaken at Bundaberg Sugar's Fairymead plantation in a crop of Q135 yielding approximately 110 t/ha. The aim of the trial program was to assess the operational performance of the system under commercial conditions. The trial program incorporated measurements of pour rate, EM and cane loss. During this testing phase a number of operational problems with the system design were encountered but no problems with belt tracking were experienced. These operational constraints compromised the trial program and only limited data were collected and analysed. The operational issues encountered will now be discussed in detail. Figure 3 illustrates the proof of concept elevator during field trials.

Figure 3: Proof of concept prototype undergoing field evaluation.

3.3.2 Elevator bowl problems

A fundamental requirement of the system is to commence operation with a full bowl of material because no storage is possible between the hugger belts. The chain and slat arrangement in the bottom of the bowl provided improved feeding to the base of the hugger belts compared to the belt conveyor. However, the system pour rate was still limited to 60 t/hr, which is below the design pour rate and that of a conventional elevator at 70-90 t/hr. This proved a major limitation to the performance of the system. The limiting factor was the jamming of material between the feed roller and the conveyor floor, resulting in stalling of the feed roller. Further modifications to this feed roller were deemed necessary to provide a more even feed.

3.3.3 Hugger belt problems

Belt tracking instability had been a significant issue with the proof of concept system. Modifications to address the problems identified in section 3.1 overcame some of the fundamental issues with maintaining belt stability. In the initial stages of the field trials the system performed extremely well. However, over time, significant foreign material buildup between the bottom belt and the backing plate, and on the rollers on the top and bottom belts, was experienced. This had a direct effect on the belt tracking and resulted in a number of additional problems including:

- high wear on the backing and side plates. The backing plates were fabricated from low density polyethylene (LDPE), 10 mm thick. However the wear rate of this plastic would not be commercially acceptable. Side plates were utilised to constrain material, but frequent rubbing by the belt edge caused excessive wear of these components;
- sagging of backing plates. This affected the pinching action of the belts and severely impacted on their ability to elevate material. Figure 4 illustrates the sagged backing plate and additional PVC ribbing fitted to provide support;
- belt wear. The instability of the belts exacerbated belt edge wear because frequent rubbing against the side plates occurred. At times, the material buildup contributing to the poor tracking caused stalling of the belts.

Figure 4: Sagged backing plate and support ribs.

Foreign material buildup included combinations of whole billets, trash and dirt. The causes of foreign material buildup included:

- whole billets escaping from between the hugger belts and migrating to underneath the bottom belt. This attracted additional trash and caused a rapid build up of material;
- exhausted air from the secondary cleaning chamber was directed down underneath the mainframe. The EM removed by the cleaning system was therefore directed parallel with the moving components, resulting in some material being deposited on these components. In addition, the disturbance of trash already deposited on the ground by the air blast exacerbated the situation.

Figures 5 and 6 illustrate the foreign matter buildup between the bottom belt and the backing plate and the bottom roller and belt, respectively.

Figure 5: Trash, dirt and whole billet buildup between the bottom belt and the backing plate.

Figure 6: The foreign matter buildup between the bottom roller and belt.

A major redesign of the hugger belt system was deemed necessary to overcome the abovementioned operational and performance issues. The initial design had pushed the functionality envelope too far in the way we had attempted to use the curvilinear path hugger belt system to achieve the required trajectory of the cane as it exits the belts. This system offers a number of advantages over more linear belt trajectories, including high tensions to be induced on the thin mat of cane via the inherent curved geometry of the belt and optimum material presentation to the cleaning chamber. However, the functionality problems of this design were too numerous to overcome.

The field testing program was useful in addressing the goals of the project, but also indicated that a number of very significant concept changes were required in the new prototype. Given the problems encountered, it was decided to adopt a more conservative approach to the belt geometry. This resulted in the development of a system with a more linear belt layout. The design criteria developed for the pre-production prototype will now be discussed.

3.4 Pre-production prototype: design criteria

3.4.1 Elevator bowl

The performance of proof of concept bowl and conveyor system was according to expectations, but minor modifications to the overall design were deemed necessary to enhance its performance, ease of maintenance and robustness.

The chain and slat arrangement in the bottom of the bowl provided adequate feeding of material to the transition zone before the hugger belt system. Minor design modifications were made to enhance the reliability, ease of maintenance and reliability. These included slat design, sprocket/shaft design, and hydraulic motor location and assembly.

The open mesh design of the bowl sides was modified to allow improvements in airflow to the primary extractor. The concentric cone sides were expanded and a larger diameter perforated mesh was used. This increased the storage volume from 0.9 m^3 to 1.0 m^3.

To maintain an open arrangement and prevent airflow restriction to the primary fan, all hydraulic piping was routed under the turntable to keep it away from the bowl. In addition, hydraulic swivels were mounted on the base to eliminate the need to put hydraulic piping around the basket.

To increase the aggressiveness of the material flow system the spiral wrapped roller was modified. The spiral wrapping on the left- and right-hand sides was modified to be 180 degrees out of phase. This metered the material more evenly and prevented material jamming under the roller.

3.4.2 Frame and hugger belt system

The hugger belts were accessed from Beltreco, a materials handling company and collaborator on BSS210. The belts were manufactured from conveyor grade PVC with specifications PVG 120/SI/Z. The belts had a diamond tread pattern to aid gripping of the material and were approximately 3 mm thick. The top and bottom belts were 8,915 mm and 7,535 mm continuous length, respectively.

3.4.2.1 Belt width

The buildup of foreign material around the hugger belts was a primary concern. The approach to overcome this problem was to increase the width of the belts. The constraints of the overall spatial envelope of the elevator dictated a maximum allowable belt width of 1,200 mm. This was an increase of 300 mm from the 900 mm belt width on the proof of concept system. However, the material was still confined to a 900 mm band. The width of a conventional chain and slat elevator is 900 mm.

It was believed that the increase in belt width would:

- eliminate the need for sidewalls to confine the material. This simplifies the complexity of the module, reducing weight and cost;

- the elimination of sidewalls, along with a redesign of the backing plate system, reduces the material escaping from between the belts and thus reduces the potential for material to be trapped under the belts;

- the increase in belt width allows presentation of the material in a wider band for the secondary cleaning module. This could be anticipated to further enhance the cleaning performance of the unit.

3.4.2.2 Belt tracking

Belt tracking stability is a fundamental criterion for the successful operation of the hugger belt system. Modifications to the proof of concept system demonstrated that maintaining belt stability would not be an issue if the following criteria and modifications were incorporated into the new development.

- Frame misalignment. The foundation to belt stability is ensuring that the head and tail rollers of both belts are parallel and that the frame has sufficient torsional rigidity. This could be fully addressed in the design stage and maintained during fabrication with the use of specifically designed jigs.

- Idler roller location. Positioning of the idler rollers to minimise foreign material buildup was an important consideration. Minimising buildup also minimises the opportunity for belt misalignments from this cause. This provided some relief of the problem and was an important consideration in the design criteria.

- Roller crown. The crown on all the rollers was designed to be approximately 4 per cent of the diameter. This degree of crowning is approximately twice that of the crowning on standard idler and drive rollers.

- Self-steering rollers. Idler rollers with self-steering capabilities to guide the belts actively were deemed an essential component in maintaining belt stability. Figure 7 illustrates the self-steering roller connected to tactile guidance system.

- Tactile guidance system. To maintain an adequate response time for the self-steering rollers a simple belt position feedback system was an essential component. Figure 8 illustrates the nylon belt position feedback guide.

Figure 7: Self-steering roller connected to tactile guidance system.

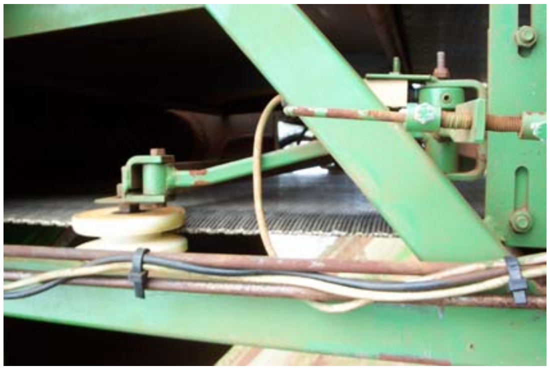

Figure 8: Nylon belt position feedback guide.

- In addition, ducting of clean air from the secondary cleaning system was utilised to exhaust loose trash and dust away from the belts. This was an additional criterion to assist in reducing foreign material buildup.

3.4.2.3 Frame design

A fundamental change in the hugger belt system was deemed necessary to overcome operational and performance issues. The proof of concept system utilised a curvilinear path for the belt system to achieve the required trajectory of the cane as it exits the belts and to maintain high tensions on the thin mat of cane. The operational problems encountered during field testing led to design staff re-evaluating the use of this belt geometry. To reduce the impact of these problems, it was decided to adopt a more conservative approach, resulting in the development of a more linear belt layout. Due to this new belt geometry a complete redesign of the frame was necessary.

Key points relating to the design of the frame were:

- the design layout was based on a truss frame with all the components attaching directly to it via fabricated brackets. The rollers provided additional stiffness of the frame;
- the truss was designed with no side walls and to be open as possible;
- the hugger belt arrangement consisted of a top belt running against a bottom belt, which ran on a removable backing plate;
- the top hugger belt was tensioned by a large diameter tail roller, spring loaded in two planes. This was to allow the opening between the hugger belts to adjust to the amount of cane being conveyed, maintaining automatic adjustment of the belt tension.

The frame and all associated components were fabricated at BSES Bundaberg. Figure 9 illustrates the truss design, which incorporates the hugger belt system.

Figure 9: Hugger belt open truss frame during construction.

3.4.2.4 Rollers

Drive rollers for the top and bottom belts were designed and fabricated by BSES. The drive rollers were single motor and double motor drive for the top and bottom belts, respectively. Both were fabricated from 168 mm outside diameter pipe with a 4.5 mm wall thickness and 1,325 mm in length. The rollers were sent away to be hot-rubber lined with 10 mm of BTR1410 and diamond grooved.

The top belt tail roller was fabricated at BSES with specifications including a diameter of 266 mm diameter, 1,300 mm in length, and supported in a floating cradle.

The bottom belt tail roller was a standard off-the-shelf conveyor idler roller of Proc manufacture. The roller specifications included a diameter of 152 mm, 1,325 mm in length and hot-rubber lined with 10 mm of BTR1410 with diamond groove.

Idler rollers were standard off-the-shelf conveyor idler rollers of Proc manufacture. The roller specifications included a diameter of 152 mm, 1,325 mm in length and hot-lined with 10 mm plain BTR1410 rubber.

3.4.2.5 Backing plates

The backing plates were fabricated from 1.2 mm stainless steel sheeting. The plates were mounted on a steel and pipe frame for ease of assembly and removal for cleaning if required. Three plates in total formed the backing system with spacings of 300 mm, 250 mm and 550 mm separating the lower, centre and upper plates, respectively.

3.4.2.6 Trash chute

The trash chute directs the flow of trash away from the bin and on to the ground. The proof of concept system trash chute was manufactured from medium density polyethylene (MDPE), 10 mm plastic. This design proved to be too rigid and was replaced with a flexible chute manufactured from PVC conveyor belting. Contact damage by the haulout bin was minimised with this system.

3.4.3 Secondary cleaning system

The fundamental specifications of the secondary cleaning system were not changed and incorporated twin axial fans on a common shaft supplying air to each end of a concentric cylinder. The air exited the cylinder from a tangential draw-off duct. The entry characteristics and placement of the secondary cleaning module were modified to allow correct airflow presentation to the material exiting from the redesigned hugger belt system.

The modifications included turning the fan 180 degrees to bring the weight closer to the harvester and reduce the overturning moment, redesign of the draw-off duct and mounting sections.

The discharge chute of the secondary cleaning module was also modified to allow more control over the discharge of trash.

Figures 10 and 11 illustrate the original and redesigned secondary cleaning system layout.

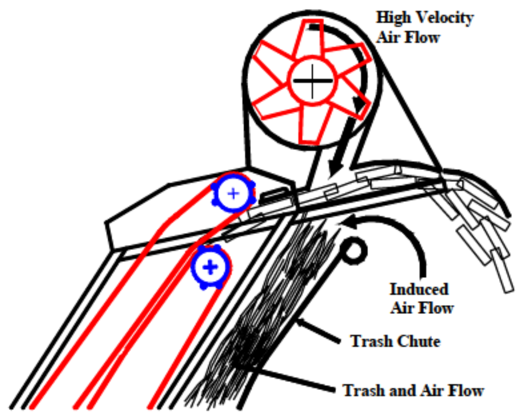

Figure 10: Original secondary cleaning layout.

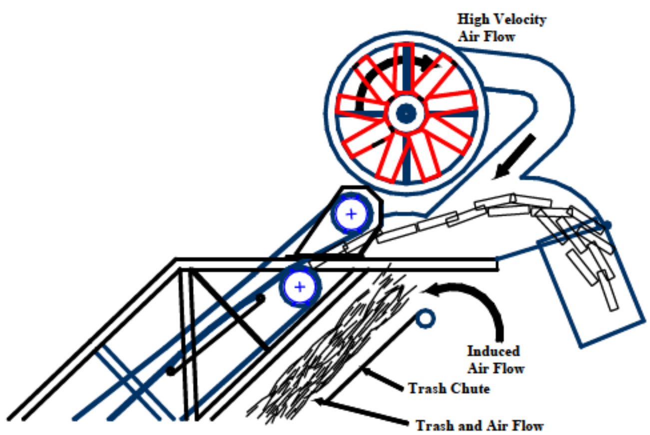

Figure 11: Redesigned secondary cleaning layout.

3.4.4 Bin flap

Control of the material as it exits the belts was an important consideration. The material exits the belts at around 7 m/s (25 km/hr), which gives a theoretical trajectory range of approximately 4 m.

The design of the bin flap to direct material into the bin was convex in shape with wrap around sides for better material confinement. In addition, the flap was hydraulically adjustable for material control and direction.

4.0 RESULTS AND DISCUSSION

4.1 Pre-production prototype assembly

The first stage of the prototype design involved modifications to the base, fitting the base to the turntable, and fitting the completed assembly to the harvester.

The components necessary for the manufacture of the hugger belt system were sourced, including steel for the frame, rollers, belts and hydraulic components. The fabrication of the frame was completed and the rollers, belts and backing plates assembled.

Modifications to the secondary cleaning system cowling, to allow assembly to the frame and to maintain correct airflow presentation to the material exiting from the hugger belts, were undertaken.

After modifications and assembly of the individual components, the secondary cleaning system was attached to the frame and this unit was assembled to the bowl arrangement. Hydraulic drive to the motors and valves was then fitted and plumbed into the dedicated variable speed hydraulic pump.

Commissioning trials of the system were then undertaken to run in the hydraulic motors and belts. These trials were undertaken in the workshop before commencing initial field trials. Figure 12 illustrates the operational pre-production prototype in initial field trials.

Figure 12: Pre-production prototype operating in initial field trials.

The final design specifications of the base, frame and secondary cleaning system and details of initial testing of componentry with respect to the design and performance criteria follow.

4.2 Elevator bowl assembly

A standard 1994 model elevator turntable was acquired and modified to allow mounting of the bowl arrangement. Modifications included removal of the hinge points and trimming by 180 mm (90 mm each side) to provide additional clearance and positioning of the attachment brackets for the bowl arrangement.

The bowl arrangement was fabricated to incorporate the chain and slat conveyor. The basis of the arrangement is an outer shell fabricated from 5 mm plate with suitable stiffeners for rigidity. Around the periphery of the shell are mounted the concentric mesh sidewalls for the bowl. The chain and slat conveyor is mounted inside this shell. Figure 13 illustrates the primary elevator bowl and turntable arrangement.

Figure 13: Primary elevator bowl and turntable arrangement.

4.2.1 Bowl performance

The chain and slat arrangement and modified feed system provided adequate feeding of material to the hugger belt. The spiral wrapped feed roller performed well by maintaining an even spread of material to allow even distribution on to the belts, and prevented bridging of material. Reliable start up operation from a full bowl of material under a very wide range of EM levels and operating conditions was achieved.

The performance of chain and slat conveyor system was considered to be commercially viable with only minor modifications to the overall design required to enhance fabrication, production, maintenance and robustness.

The open mesh concentric cone design of the bowl sides was developed to improve the airflow to the primary extractor. Figure 14 illustrates the airflow characteristics of a primary extractor when fitted with a standard elevator. Figure 15 illustrates the airflow characteristics of the identical primary extractor when fitted with the open mesh bowl and chain and slat arrangement. The width is defined when the bowl is viewed from the rear of the harvester and the depth is defined when viewing the bowl from the side.

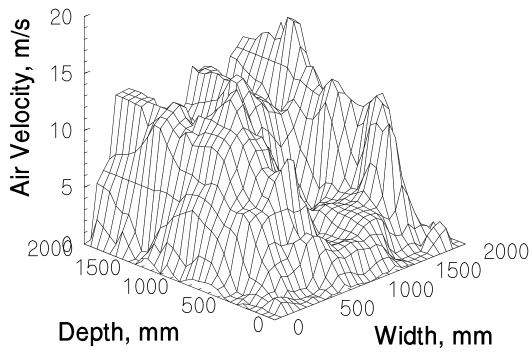

Figure 14: Airflow distribution of the primary cleaning system on the SRDC/BSES 7000 research harvester when fitted with a standard elevator. Fan speed of 1200 rpm at no load.

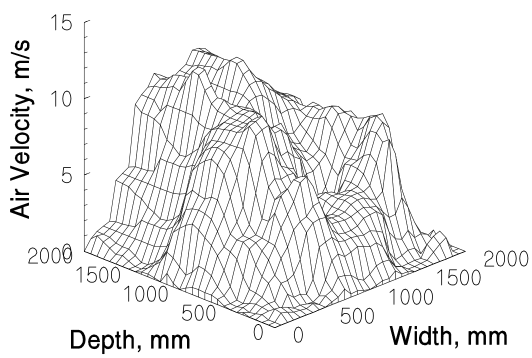

Figure 15: Airflow distribution of the primary cleaning system on the SRDC/BSES 7000 research harvester when fitted with the open mesh bowl chain and slat arrangement. Fan speed of 1200 rpm at no load.

The airflow in the extraction chamber is uneven when a standard elevator is fitted as shown in Figure 14. Higher velocity airflows are experienced immediately proceeding the chopper exit, which taper off towards the rear of the bowl. The peak airflows of up to 20 m/s were measured at the outer edges of the bowl. The lowest airflows were in the order of 5 m/s.

A more even airflow distribution was measured when the open bowl of the pre-production prototype was fitted as illustrated in Figure 15. The mean airflow was in the order of 10 m/s. This can be attributed to the open mesh design, which allows a more even air entry conditions. The improved airflow distribution from the primary extractor will allow a reduction in fan speeds to achieve improved cleaning performance. The lower fan speeds will also reduce cane loss.

4.3 Frame and hugger belt system

The frame was fabricated in a truss design to maximise structural integrity. On completion of the frame, the backing plates, rollers and belts were installed. Belt tracking and tensioning systems were then installed.

4.3.1 Belt tracking reliability

Initial trials were undertaken under controlled workshop conditions. The belt was continuously operated at varying belt speeds (4-7 m/s) under no load and loaded conditions. In addition, self-steering rollers were manually adjusted out of alignment. Belt stability and response time of the self-steering rollers to regain belt stability were monitored.

These trials demonstrated that the issue of unstable tracking of the belts was resolved. Therefore, by incorporating the design criteria including wider belts, self-steering rollers with tactile feedback system, and via attention to the fabrication of the frame and assembly of components, improved belt stability was achieved.

For additional operator feedback, switches were triggered to warning lights in the cab to alert the operator if the belts had run off for extended periods.

4.4 Secondary cleaning system

The modifications to the secondary cleaning system were undertaken and the system set up on the hugger belt frame. The hydraulic drives for the bowl conveyor, hugger belts and secondary cleaning system were then installed.

Initial trials were aimed at benchmarking the airflow characteristics at the entry and exit points of the modified system. These where compared with the airflows measured on the proof of concept system to ensure that the performance of the fans had not been compromised after the design modifications. A comparison of the airflow characteristics of a standard secondary extractor and the pre-production prototype secondary cleaning system was undertaken. Figure 16 illustrates the airflow characteristics of a standard secondary extractor type cleaning system. The width is defined when the secondary extractor is viewed from the rear with the elevator straight out the rear of the harvester. The depth is defined when viewing the extractor from the side.

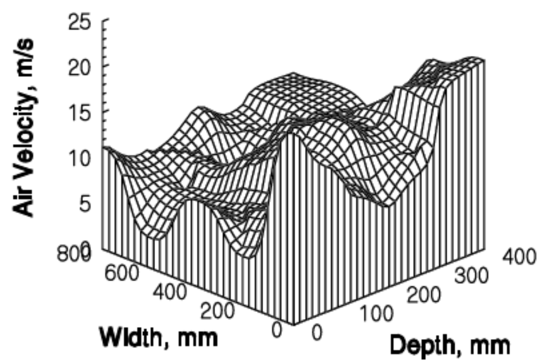

Figure 16: Airflow characteristics of a standard secondary cleaning system system. Fan speed of 1720 rpm at no load.

The airflow is characterised by low air velocities in the centre of the chamber, higher velocities towards the rear, and velocity peaks at the outer edges. This airflow characteristic would typically result in poor trash separation and high cane loss.

To characterise the airflows in the pre-production prototype secondary cleaning system the airflow distribution at three cross-sections was measured. These positions included the exit of the ducting, and at the entry and exit points of the trash chute. Figure 17 illustrates the cross-sections where the airflow distributions were measured.

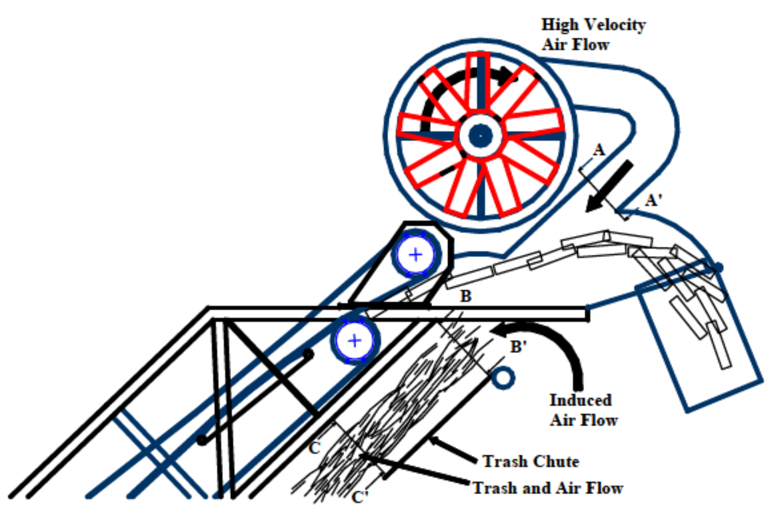

Figure 17: Location of cross-sections where airflow distributions were measured.

Figures 18, 19 and 20 illustrate the airflow distributions at locations A-A', B-B' and C-C' (see Figure 17), respectively. The width is defined when the cleaning system is viewed from the rear with the elevator straight out the rear of the harvester. The depth is defined when viewing the cleaning system from the side.

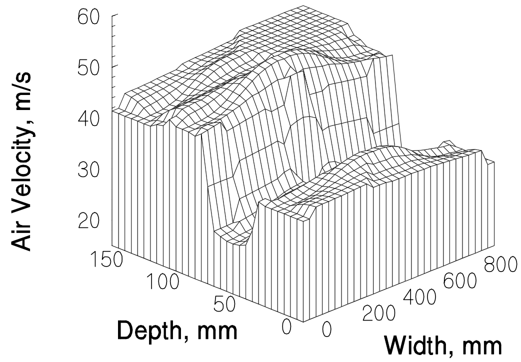

Figure 18: Airflow distribution at section A-A'. Fan speed of 2150 rpm at no load.

The airflow distribution at section A-A' is characterised by a narrow air blast with a velocity of approximately 40 m/s, which impacts the cane flow at the moment it exits the hugger belts. This high velocity air-curtain has maximum effect on the trash particles and little effect on the billets. The airflows were comparable to the design specifications in Davis and Norris (2000).

In addition, the airflow distribution at the entry and exit points of the trash chute was measured to determine the impact of the induced air flow and edge effects of the chute design. The system was designed so that an increase in the volume of air over that exhausted from the fan is delivered down the chute. Figure 19 illustrates that the design criteria have been achieved in that additional air has been induced in this region. The increase in air velocity in the centre is due to the edge effects of the chute. This inherent design characteristic allows an increase in airflow in the area of maximum billet concentration to optimise trash separation.

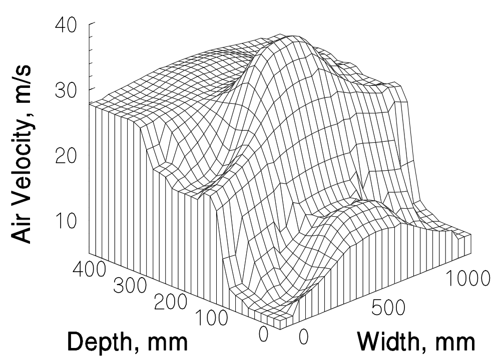

Figure 19: Airflow distribution at section B-B'. Fan speed of 2150 rpm at no load.

It is desirable to dissipate the airflow at the exit of the trash chute to prevent agitation of the trash already on the ground surface. Figure 20 demonstrates that there still remains a relatively high air velocity exiting the chute. It is proposed to install baffles inside the chute to further dissipate the airflow.

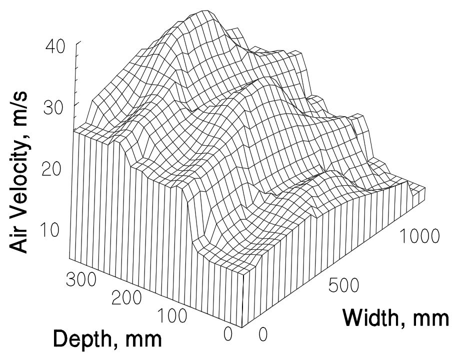

Figure 20: Airflow distribution at section C-C'. Fan speed of 2150 rpm at no load.

4.5 Overall weight and weight distribution

The design and development of the pre-production system were based on overcoming the functionality and operational problems associated with the proof of concept system. Minimising weight was not a fundamental criterion during this phase because future finite element analysis could address this issue. The finite element analysis was not undertaken since the project investigators believed that it was too premature given the limited testing program completed. There is confidence that appropriate engineering design and finite element analysis can result in a strong, rigid, lightweight structure.

The weight of the current pre-production prototype with secondary cleaning system is approximately 1,400 kg, compared with approximately 1,500 kg for the conventional chain and slat elevator. The weight distribution is base (with no turntable) 430 kg, frame and hugger belts 790 kg and secondary cleaning system 190 kg. Most significantly, approximately 190 kg of the weight reduction is in the secondary cleaning system (190 kg versus 285 kg). The complete secondary cleaning system will be manufactured from plastic, further reducing its weight.

Since most of the weight reduction in the current design is associated with the secondary cleaning system, the centre of gravity for the high-speed elevator is closer to the harvester than for the conventional elevator. The resulting 20 per cent reduction from approximately 31 kNm to approximately 25 kNm in the overturning moment is important from harvester operational considerations. This reduction significantly enhances stability of the machine, particularly in sloping conditions. The pre-production prototype system weighs approximately 90 per cent of the weight of a conventional elevator, but with a substantially more desirable position of the centre of gravity, further enhancing the advantage of the reduced weight.

Comments from operators of the harvester are extremely positive as to the noticeable improvement in machine stability whilst harvesting and during road travel.

It is anticipated that, with further development, including the fabrication of more components from plastics and finite element analysis, the final weight will be further reduced and weight distribution improved.

4.6 Operational and performance testing

SRDC conducted a review of the progress of this project in August 2001. The full report on this review can be found in Appendix 1.

The field testing program was undertaken during September and October 2001 after the completion of the SRDC review.

4.6.1 Initial field testing

The elevator was used to harvest on-station research trials and commercial cane on a neighbouring farm at Kalkie. Approximately 500 tonnes of cane were cut during this phase and this equated to approximately 36 operating hours. Crop size was typically 100-120 t/ha, and the topper was deliberately not used to maximise EM levels in cane delivered to the secondary cleaning system. Pour rates were monitored by the use of a weighing tipper and time required filling the bin.

These trials were to assess the mechanical and functional performance of the system. Blue tarp tests were undertaken to obtain an indicative cane loss estimate. The following observations were noted:

- cane loss was low (1.5-2 t/ha), with the major source of loss being spillage between the elevator and the bin. However some spillage from the belts did occur at high pour rates;
- EM levels were very low in the harvested product. The short billet length (160-170 mm) and high throw velocity resulted in average loads of 5.5 tonnes in the 4 tonne (nominal) tipper bin;
- at high pour rates, problems with the belts slowing down were experienced. This was identified as being caused by loading of the lower chain and slat conveyor because of dirt and trash buildup under damp conditions. Additional modifications to the clearances in this area alleviated this problem;
- when the elevator was operated at its steepest angle (50 degrees) for harvesting 1.5 m row cane, problems with feeding of the belts were encountered. However, when the elevator angle could be reduced to 45 degrees, this was not a problem;
- when harvesting 1.5 m rows, the maximum pour rate, which could be reliably maintained, was 78-80 t/hr;
- when harvesting 1.8m rows or plough out where the haulout was able to move out slightly, pour rates of 120 to 140 t/hr could be maintained consistently without problems. These are commercially acceptable pour rates. In workshop testing of the proof of concept prototype developed in BSS210, pour rates of this magnitude were achieved in whole billeted cane, but the capacity of this unit is demonstratably higher. Figure 21 illustrates the pre-production prototype operating.

Figure 21: Operational pre-production prototype.

4.6.2 Commercial field testing

On completion of the initial field tests, the mechanical functionality and performance of the system were deemed robust enough to be released to a contractor for further testing under commercial conditions.

The harvester was transported to Alpeche Farms, Childers. This farm was chosen because the area proposed to be harvested was dual row (1.8 m spacing). The harvester was operated by Peter Bonnano who is a grower and harvesting contractor.

For this stage of the testing, the harvester was also fitted with the prototype counter-rotating fan system, to evaluate its performance in conjunction with the pre-production elevator system.

An intermittent but persistent problem with the 'Murphy' safety shut-down system on the harvester was encountered during this stage of the testing, meaning that significant time was lost until the fault was finally identified and repaired.

Instead of harvesting the anticipated several thousand tonnes of cane, only approximately 600 tonnes of cane were harvested before the machine had to be moved on because of commitments to the BSES plant breeding program. Due to this no cleaning performance data were measured.

The operator made a number of both positive and negative comments. Positive comments included:

- the weight distribution of the elevator gives a very noticeable improvement in machine stability, particularly in the undulating country in which they were operating;

- separate elevator bowl appeared to work well; however, its capacity for storage of cane was probably greater than is needed;
- bin weights in excess of 1.5 tonnes higher than with his harvester were achieved. Whilst some of this was billet length effect, the low EM and high billet velocity were also significant contributors.

Negative comments included:

- at very high pour rates (140 t/hr), the entire cleaning system overloaded, and EM levels increased dramatically. This effect may have been able to be alleviated if the primary extractor fan speeds had not been limited to approximately 1050 rpm to limit potential for cane loss;
- at high pour rates and with high EM in the material being supplied to the secondary cleaning module cane loss was deemed to be unacceptably high (in trials under BSS189 and BSS227, under conditions similar to this, cane loss from the current secondary extractor system can significantly exceed 7 per cent);
- problems with cane loss out the sides of belts were significant at very high pour rates; however, it was suspected it was related to belt speed slowing, particularly where gluts occurred. Inconsistent belt tension was also noted as an issue that potentially impacted on cane loss;
- problems were encountered with feed at high pour rates when elevator in higher positions;
- excessive dust from the secondary cleaner air blast.

The harvester was operated for approximately 52 hours by BSES for harvesting plant breeding and associated trials. The belts were continually operated even when the machine was not actually harvesting cane.

Comments from the operators included:

- significantly improved machine stability both in the field and during road travel;
- high bin weights and low EM levels.

Significant areas of concern related to:

- excessive dust blown up by the air blast from the secondary cleaner;
- an apparent problem with belt tension;
- associated problems with cane loss from sides of belts.

Blue tarp tests were undertaken to determine levels of cane loss. The average cane losses from the primary extractor and secondary cleaning system were 4.5 per cent (4.3 t/ha) and 1.7 per cent (1.6 t/ha), respectively. These low losses are promising for the operating conditions, and in view of the low levels of trash observed in the cane supply.

4.6.3 Operational problems

On completion of the crushing season the harvester returned to the BSES workshop. The elevator was partly dismantled to evaluate wear on components and to identify causes of problems noted during field operation.

A number of issues were identified leading to design changes and modifications being undertaken to enhance its operation during the 2002 harvesting season. The issues and modifications included:

- mechanical performance of the chain and slat elevator was reduced due to the slats bending and colliding with the bottom reinforcing plates on the base. The bottom of the slats was reinforced to overcome this problem;
- dirt or mud buildup underneath the slats was an issue. The bowl frame was modified to allow more clearance between it and the slats;
- trash built up on the frame of the top belt head roller. The roller frame was modified to provide more clearance;
- buildup of trash under the bottom belt on the lower backing plate. The back plate was modified to allow a 250 mm gap in its centre to assist in the removal of foreign material;
- containment of billets between the belts. Some billets were escaping from between the belts and to overcome this, small wheels were placed on the belt sides to pinch them closed. Two wheels were located at the bottom of the elevator and two at the top end. In addition, an improved billet deflector was fabricated and installed to keep the billets centred;
- billets would hit the fan cowling at the back of fan opening. The cowling was modified to provide more clearance. The drive roller of the top belt was repositioned further back and lowered to change the trajectory angle;
- the exhausted air and EM from the secondary cleaning system blowing up dust and trash from the paddock were seen as a problem. Modifications to the trash chute were undertaken to direct the material further away.

Additional modifications were made to the tail roller of the top elevator belt. This belt was tensioned by a large diameter roller, spring loaded in two planes. This was to allow the opening between the hugger belts to adjust to the amount of cane being conveyed whilst maintaining adjustment of the belt tension. Figure 22 illustrates the single large diameter tail roller.

Figure 22: Hugger belt entry system with single large diameter tail roller.

During testing it was found that the top belt spun intermittently on the material before it gripped it and was taken in. This increased the wear in the middle of the belt and was not conducive to consistent feeding.

The geometry of this area was redesigned to incorporate more of a tapered entry condition. The single roller was removed and two smaller rollers in a parallelogram arrangement were set up. Figure 23 illustrates the reconfigured entry of the hugger belt system. This new design is yet untested; however, it is expected to perform better when operating the elevator at steeper angles.

Figure 23: Reconfigured entry geometry of the hugger belt system incorporating twin tail roller arrangement.

The field trials indicate that the problems associated with the proof of concept system developed in BSS210 have been largely overcome. Engineering solutions have been developed to overcome the problems of elevator feeding from the redesigned bowl and hugger belt tracking.

From the limited testing undertaken, the mechanical reliability and functionality of the pre-production prototype are approaching a commercial level. The very limited performance testing suggests an improvement in cane loss relative to the level of cleaning achieved. The system offers the option of optimising the primary extractor for minimum cane loss and allowing the secondary cleaning system to take a greater role in controlling final EM levels.

This is achieved within the constraints of a compact cleaning module that is light and has few wearing parts. The high efficiency of the blower fans is maintained because trash does not pass through them causing wear or adversely impacting on blade aerodynamic profile.

5.0 DIFFICULTIES ENCOUNTERED DURING PROJECT

A number of difficulties were experienced throughout the duration of the project which impacted on the final outcome. These difficulties included:

- a significant delay in the testing of the proof of concept system due to the time taken in development of belt tracking solutions. The system was tested late during the 2000 season and it was deemed necessary to fully evaluate the proof of concept system before the next prototype was designed and fabricated;

- the delays in field testing the proof of concept system delayed the design of the pre-production prototype. Fabrication was commenced in late January with complete assembly achieved in August. This impacted on the time available to undertake field trials due to the short crushing season in 2001;

- these time constraints also meant that the project leader was not available to undertake initial trials of the system, or to run the testing program, because of other commitments.

Field trials of the pre-production prototype commenced in September 2001. The number of trials and operating hours achieved were somewhat lower than desirable, resulting from:

- the early end to the season, with the associated pressure on the BSES trial harvesting program and contractors;
- the logistics of machine movement, including the need to fit in around the harvesting of BSES trials with associated lost time for machine cleaning and sterilisation;
- an intermittent but persistent problem with the 'Murphy' safety shut-down system on the research harvester, meaning that significant time was lost some days until the fault was finally identified and repaired. This difficulty had maximum impact during testing of the machine by Alpeche Farms.

These problems resulted in the test program not effectively quantifying the EM and cane loss characteristics of the system.

Due to the limited testing undertaken, the mechanical and functional reliability could not be fully evaluated. It was therefore deemed premature to undertake a full finite element analysis of the structure because the design may have required minor changes.

6.0 RECOMMENDATIONS FOR FURTHER RESEARCH

A significant research and development (R&D) program has been undertaken over the past four years on the development of a high-speed elevator and advanced secondary cleaning system. Project BSS210 evolved the concept and demonstrated its potential, with this project developing solutions to the identified problems. The pre-production prototype developed in this project has been demonstrated to be mechanically and functionally reliable.

The development of the prototype system is the most radical development in cane harvester technology in at least two decades. The system offers dramatic improvements in cleaning, reduced cane loss, and operational advantages of reduced weight and enhanced machine stability, and can be retrofitted to current harvesters.

Further development is required to build on the significant gains made throughout this project to translate this prototype into a commercially viable production unit. Whilst it can be argued that the further development of the system should be the responsibility of industry, this is not relevant for developments such as this. Limited sales prospects for new machines in the foreseeable future limit the interest by harvester manufacturers in significant R&D expenditure. As the greatest impact of the unit in the industry will be via the retrofit market, an exclusive arrangement with a manufacturer will also limit the potential availability of the system to the industry.

BSES has recognised the potential of the system and has committed funds for the further testing and commercialisation of the system during the 2002 crushing season. This project will progress the system to commercial availability by:

- evaluation of the pre-production prototype under commercial conditions and in different operating environments for the entire 2002 season;
- finalising the design of production units in conjunction with the selected manufacturer.

The product, being significantly different to the traditional chain and slat elevator, offers major challenges for manufacturers during this phase of development. Experience with the commercialisation of BSES fronts, and products such as the cane loss monitor, is that the R&D organisation must maintain close control of the product during this beta testing phase, if compromises which significantly reduce the performance are to be avoided. Similarly, the release of products that have come from R&D programs, are of appropriate technology, but have not been adequately beta tested (eg the cane loss monitor) has led to failure commercially, despite the considerable advantage they offered the industry.

7.0 APPLICATION OF THE RESULTS TO INDUSTRY

High levels of EM in the cane supply are known to reduce ccs levels at a cost to growers. High EM is also a cost to millers through low bin weights, increasing cost of transport, and reduced cane crushing rate. More specifically, the reduction in EM of cane entering the factory has been clearly demonstrated by many other researchers to both increase mill throughput, without additional capital investment, and positively impact on sugar quality. In addition, cane loss is an economic problem for the whole industry and loss of sugar during harvesting is a potential environmental issue if this material enters waterways following heavy rainfall.

This was a joint project between manufacturers and research organisations. It focused on a commercial outcome, and included both technology development and transfer. Collaboration between the stakeholders has been used to advantage in this project. It has involved the integration of two significant and complementary developments into one harvester component.

The project offers significant potential advantages for all sectors of the sugar industry.

To the harvester manufacturer the concepts offer:

- a reduction in weight of a major component of the harvester. The reduction in elevator weight improves machine stability and will allow subsequent weight reduction in other harvester components;
- an increase in dimensions available for the cleaning chamber, and the potential to move the elevator further to the rear, allowing incorporation of further development in primary cleaning technologies;
- a cost effective retrofit to current harvesters.

To harvester operators the concepts offer:

- a significant opportunity to reduce cane loss and EM levels;
- the redesigned bowl allows lower fan speeds of the primary extractor and, coupled with the use of a blower based cleaning system, is likely to reduce cost to harvester operators.

These advances flow on directly to the whole of industry through better harvester performance and lower harvester weight and advanced cleaning.

The product being developed will enhance the adoption of best practice because it will:

- reduce both cane loss and EM from harvesters to which it is fitted, because of its enhanced capability to remove EM whilst minimising cane loss;
- encourage the adoption of better farming systems such as dual row planting. Currently, machine instability is a major disincentive to the fitting of longer elevators, which are essential for successful outcomes in dual row cropping systems. With this system, an extension of length is not needed for harvesting dual row cane. The light weight and low overturning moments of the design (thus dramatically improving harvester stability) allow the harvester operator scope for higher productivity in sloping operating conditions.

It is highly relevant to the industry in its current situation because it is applicable as both an option on new machines and as a viable retrofit on current machines, in lieu of the periodic rebuild of the standard elevator.

This project is clearly addressing the high priority areas of SRDC's Harvest and Transport Program of reducing EM, reducing cane and sugar losses, and enhancing cane quality. In addition, the lighter elevator will increase stability of harvesters, as well as helping to reduce compaction of soil.

A successful outcome of this project will also demonstrate the potential for the application of these alternative concepts for post-harvest cleaning of cane at the mill.

8.0 PUBLICATIONS ARISING

This project was a collaborative venture between BSES and two commercial companies. Therefore all information was considered confidential and there have been no publications to date due to the Commercial-in-Confidence nature of the project.

9.0 INTELLECTUAL PROPERTY

This project is treated as Commercial-in-Confidence. CNH Austoft has the rights to commercial use of the technology for an exclusive two-year period, should they wish to exercise that right. IP may be protected by registering the final design, because the concepts of high-speed hugger belts and blowers are not new.

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11.0 ACKNOWLEDGMENTS

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The project was conducted in conjunction with key commercial stakeholders, including BSES, Gough Plastics and CNH Austoft. The author would like to thank those involved from these organisations including Andrew and Simon Gough (Gough Plastics), Mal Baker, Don Helmrich and Richard Trudgian (CNH Austoft) for their contributions.

The authors would also like to thank Geoff Pickering for allowing access to cane for the preliminary trials. The patience and cooperation of Peter Bonnano from Alpeche Farms in facilitating the principal field harvesting trials are gratefully acknowledged.

In addition, the assistance from BSES officer Peter Gaul who undertook the development and fabrication of the prototype elevator and cleaning system is acknowledged. Peter also undertook the supervision of the field testing and performance monitoring. The assistance of Les Poulsen and Phil Netz, who assisted with the performance monitoring, is also gratefully acknowledged.

APPENDIX 1

CONFIDENTIAL

SRDC REVIEW REPORT ON PROJECT BSS251

Project number: BSS251

Project Title: Commercialisation of lightweight elevator and advanced secondary cleaning system for sugarcane harvesters.

Organisations: BSES, Gough Plastics, CNH Austoft.

Project Supervisor: Mr Chris Norris (BSES, Bundaberg).

Research Staff: Mr Rod Davis (BSES, Bundaberg), Mr Peter Gaul (BSES, Bundaberg).

Date and Place of Review: 29 August 2001, BSES Bundaberg.

Participants: Mr Ian Fraser (SRDC Director, and convenor of review), Mr Eddie Sim (EHS Manufacturing Pty Ltd, Mackay), Mr Simon Gough (Gough Plastics, Townsville), Mr Chris Norris, Mr Rod Davis, Mr Gavin McMahon (BSES, Brisbane) and Dr Les Robertson (SRDC).

Commencement date: 1 July 2000.

Anticipated Completion Date: 30 June 2002.

Project Objectives:

This project will develop and test, to commercial prototype stage, a new concept of cane harvester elevator and integrated secondary cleaning system. The proposed design offers:

- A cost-effective retrofit elevator which will significantly enhance the product quality and reduce cane loss from current harvesters
- An elevator system for new harvesters which compliments the performance of alternative cleaning system designs being developed.

Key goals of the project include:

- Design and manufacture a new prototype on the basis of knowledge gained from BS210 prototype
- Undertake extensive testing of the prototype both in the workshop and in the field to characterise performance and ensure mechanical and functional reliability of the redesigned system
- Undertake final design to include full finite element analysis of the frame to ensure structural integrity and functional reliability, and incorporate appropriate features for ease of manufacture
- Manufacture the pre-prototype and undertake a rigorous field testing program.

Conduct of the work:

The project has made significant progress towards its stated goals. The issue of unstable tracking of high-speed belts experienced in BS210 appears to have been resolved. The wider hugger belts and use of tracking rollers was demonstrated to perform well in the field. The chain and slat arrangement in the bottom of the bowl provided effective feeding to the base of the hugger belts. Cane supplied to the haulout appeared to be low in trash content, and cane loss in the trash stream was relatively low. Secondary cleaning with the blower arrangement appeared to be efficient. Primary extraction of EM may also have been improved with use of an open mesh bowl allowing better air-flow at lower fan speeds.

Relevance to Industry:

High levels of extraneous matter in cane are known to reduce ccs of the cane supply, at a cost to growers. High EM is also a cost to millers through low bin weights (and increased cost of transport), and reduced cane crushing rate. Nevertheless, some mills are capable of using additional EM for electricity co-generation.

Cane loss is an economic problem for the whole industry regardless of differences in mill handling of EM. In addition, high loss of sugar during harvesting is a potential environmental issue when the material enters waterways following heavy rainfall.

Blower technology is being successfully used for secondary cleaning on the elevator, and the technology may have additional applications in the sugar industry. Lightweight fans can be used because cane billets and tops do not contact the blades. The redesigned bowl allows lower fan speed of the primary extractor, which is likely to reduce cost to harvester operators and reduce cane loss.

This project is clearly addressing the high priority areas of SRDC's Harvest and Transport Program of reducing EM, reducing cane and sugar losses, and enhancing cane quality. In addition, the lighter elevator will increase stability of harvesters, as well as helping to reduce compaction of soil. It is estimated that the current prototype was approximately 400 kg lighter than conventional elevator/ secondary extractor units.

Future activities:

The project is on track to meet remaining Milestones, with extensive field trials planned for September 2001. These trials will evaluate performance under a range of conditions to determine reliability and to determine the refinements needed to make the elevator robust and efficient. Measurements of EM, cane loss, etc, will be undertaken on different varieties, crop sizes and crop condition including lodging. Further studies on the wear characteristics of components will be undertaken in 2001/02. Full finite element analysis will also be undertaken on the frame and components to allow a final design that incorporates strength with minimum weight.

At the end of the project (June 2002), the lightweight elevator and secondary cleaning module will not be commercially available, but will be close to completion. The project participants contend that two prototypes should be extensively evaluated throughout the

2002 harvest season, on commercial machines. The objective would be to demonstrate reliability, durability and efficiency to CNH Austoft and to Gough Plastics before commercial production. BSES may not be able to provide full funding for the two prototypes and the servicing required in 2002.

Competence of project supervisor and research staff:

Mr Norris gave a clear and concise presentation that covered the limitations as well as the advantages of the high-speed belt system, the redesigned bowl and elevator feeding arrangement, and the secondary cleaning system. Mr Norris and the project engineer (Mr Rod Davis) are commended for the excellent engineering that has overcome the problems of elevator feeding from the redesigned bowl, hugger-belt tracking, and blower cleaning of cane. High-speed hugger belt technology has been developed from other industries including coal and woodchip, and the researchers are evidently familiar with related applications in materials handling.

Expertise available in SRI with modelling of air-flow has been used to advantage in this project, as has the experience of JCU researchers in design of high-speed belts for materials handling. Collaboration between BSES, SRI, JCU, Gough Plastics, CNH Austoft and Beltrico is commendable.

Intellectual Property:

This project is treated as Commercial-In-Confidence. CNH Austoft has the rights to commercial use of the technology for an exclusive two-year period, should they wish to exercise that right. IP may be protected by registering the final design, as the concepts of high-speed hugger belts and blowers are not new.

Recommendations:

1. Explore avenues for funding the further development of two prototypes for extensive field evaluation in the 2002 harvest season under wet as well as dry harvesting conditions.
2. Refine the placement of the return trash shute during the 2001 season as proposed, to maximise the efficiency of trash and cane separation with minimum cane loss.
3. Follow the currently-agreed research plan of a) extensive field testing in the 2001 harvest season to evaluate mechanical and functional reliability, and to measure EM and cane loss characteristics, and b) finite element analysis and final design.
4. Consider static running of the chain and slat feeder system to determine wear and durability characteristics following the 2001 harvest season.
5. Determine the weight of the current prototype elevator/ secondary cleaning module.

Mr Ian Fraser (Convenor)
Mr Eddie Sim
Dr Les Robertson

31 August 2001