Quality Research, Development, and Consulting Inc.

SMART SCREENING SYSTEM (S3)

IN TACONITE PROCESSING

SEMI ANNUAL REPORT

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Q.R.D.C., Inc.
PO Box 562, Excelsior, MN 55331

Smart Screening System (S3) In Taconite Processing

Semi Annual Report

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Report Author
Dr. Daryoush Allaei, P.E.
Ryan Wartman

Report Editors
Dr. Daryoush Allaei, P.E.
Mr. David Tarnowski
Mr. Asim Syed Mohammed
Mr. Ryan Wartman

Any questions or comments regarding this report
should be directed to the principle investigator

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ABSTRACT

The conventional screening machines used in processing plants have had undesirable high noise and vibration levels. They also have had unsatisfactorily low screening efficiency, high energy consumption, high maintenance cost, low productivity, and poor worker safety. These conventional vibrating machines have been used in almost every processing plant. Most of the current material separation technology uses heavy and inefficient electric motors with an unbalanced rotating mass to generate the shaking. In addition to being excessively noisy, inefficient, and high-maintenance, these vibrating machines are often the bottleneck in the entire process. Furthermore, these motors, along with the vibrating machines and supporting structure, shake other machines and structures in the vicinity. The latter increases maintenance costs while reducing worker health and safety.

The conventional vibrating fine screens at taconite processing plants have had the same problems as those listed above. This has resulted in lower screening efficiency, higher energy and maintenance cost, and lower productivity and workers safety concerns. The focus of this work is on the design of a high performance screening machine suitable for taconite processing plants.

SmartScreens™ technology uses miniaturized motors, based on smart materials, to generate the shaking. The underlying technologies are Energy Flow Control™ and Vibration Control by Confinement™. These concepts are used to direct energy flow and confine energy efficiently and effectively to the screen function. The SmartScreens™ technology addresses problems related to noise and vibration, screening efficiency, productivity, and maintenance cost and worker safety. Successful development of SmartScreens™ technology will bring drastic changes to the screening and physical separation industry.

The final designs for key components of the SmartScreens™ have been developed. The key components include smart motor and associated electronics, resonators, and supporting structural elements. It is shown that the smart motors have an acceptable life and performance. Resonator (or motion amplifier) designs are selected based on the final system requirement and vibration characteristics. All the components for a fully functional prototype are fabricated. The development program is on schedule.

The last semi-annual report described the completion of the design refinement phase. This phase resulted in a Smart Screen design that meets performance targets both in the dry condition and with taconite slurry flow using PZT motors. This system was successfully demonstrated for the DOE and partner companies at the Coleraine Mineral Research Laboratory in Coleraine, Minnesota.

Since then, the fabrication of the dry application prototype (incorporating an electromagnetic drive mechanism and a new deblinding concept) has been completed and successfully tested at QRDC's lab.

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INTRODUCTION

Current screening machines have one thing in common: they operate using an electrical motor with a rotating unbalanced mass to generate shaking. Based on the information from Minntac Grant Application [1], Minntac has struggled with finding engineering solutions for noise and vibration problems caused by conventional screening machines. Evaluations of isolation curtains/walls, different screening machine brands, and lower speeds have resulted in minimal improvements in noise levels and have significantly compromised production. Blinding of screens is another major cause for loss in production. Minntac has estimated that approximately 2494 megawatt hours per year alone are lost due to poor screening recovery and wasted energy.

The ultimate goal of this project is to develop SmartScreens™ that will replace the inefficient massive electric motors. SmartScreens™ will have miniaturized smart motors (ceramic- or electromagnet-based). SmartScreens™ will incorporate an energy management technique to control energy flow and will confine injected shaking energy to the screen panels. In 2002, the QRDC team proposed to combine state-of-the-art smart materials, the concept of single or multi-stage resonators, and the patented energy management technique. This innovative technology has won several Research and Development awards from the U.S. Army, Navy, and Air Force and commercial organizations [2-6].

In the previous reporting periods, it was shown through computer simulations and laboratory prototypes that smart motors, accompanied by specially designed resonators, meet current screening vibration levels while simultaneously significantly reducing power consumption and energy loss. The ceramic materials and electromagnetic drives used in these motors are well suited for applying large dynamic forces and the required shaking functions to resonators. The smart motors consume 50% to 96% less energy than the bulky electrical motors, and are capable of operating over a wide range of frequencies. They are almost maintenance free, as they do not have any moving components and do not need lubrication. Additionally, smart materials (such as PZT) can function as both collocated sensors and actuators for active control of the shaking action and process automation.

In the first semi-annual report [6], it was shown that cantilever resonators of appropriate shape and size could be used to amplify the displacements and accelerations of the miniaturized ceramic motors so that the screening function was optimized. Finally, it was shown through simulations that the system can be optimized and completed by incorporating the energy management techniques that have been developed by QRDC. Energy management is composed of energy diversion, confinement, dissipation, conversion, and cancellation. It is the combination of smart materials and these vibration energy managing methods that make this approach unique and innovative.

In the second reporting period [7], QRDC was able to design, fabricate, and evaluate the key components of the SmartScreen™. The benefits of these prototypes were shown to be close to the predicted performance. They included: broader and finer control of the screening frequency, extremely low power consumption, tremendous reduction in operating noise level, and remarkable reduction in transmitted vibration from the screen to the supporting structure. The increased control over the motor frequency allowed QRDC's SmartScreens™ to be tuned for optimum operation and to be regularly changed to potentially avoid blockage or blinding of screens. Power consumption reduction allows for savings as well as increased potential number of screens to be in operation at one time. Noise and floor vibration level reductions improve worker safety as well as productivity. Additionally, reductions in vibration transmittance to the supporting structure potentially reduce floor vibrations, which may prevent interference in one screen's operation from another.

The third semi-annual report [8] shows the finalization process of the key components. that includes smart motor, resonator and supporting structure. It also details the assembly and evaluation of full SmartScreens™ system under laboratory conditions. This report also covers the details of Oscillating Mass (OM) driver to power full SmartScreens™ system and the lab test results.

The fourth semi-annual report [9] included detailed results of SmartScreens™ system test with modified supporting structure under dry and wet conditions. The lab test results of full system and vibration reduction on supporting structure was very encouraging. It also details the computer based analysis to further improve system performance in field installation and to reduce the stringent installation requirement. The report also included the results of a successful longevity test of smart motor using a quarter system while operating round the clock for over a year.

The fifth semi-annual report [10] documents significant work was done through experimentation and through computer simulations to minimize installation sensitivity and further improve system performance. Various suspensions were designed and tested both in lab and field. The lab and field test results showed significant performance improvement and less sensitivity to the installation. However system performance suffered during wet tests due to the effects of added damping. The motors did not have enough power to compensate for the losses and forced QRDC team to go back to the drawing table. There were two options, either to operate the system at a different mode which is less sensitive to external damping or to further improve system performance (overpower system) to compensate for the losses. Considering time constraints, it was decided to improve system performance. Through innovative isolation design and few other minor changes the system performance was almost doubled under lab conditions. The fifth semi-annual report also details the work done at Albany Research Center lab for strain measurement on the S3i-101 unit and the feasibility of using SmartScreens™ technology for dry application.

During the sixth semi-annual report [11], a comprehensive design refinement was completed that resulted in a Smart Screen design that fully meets project requirements. This design was tested in the lab and at CMRL. Furthermore, a demonstration of this design was also given for the DOE and partner companies, again at CMRL. Additional effort was placed into leveraging the PZT drive system to provide functionality simply not available on the market today. The report documented work done with alternative input functions to create screen motion profiles different than the traditional sinusoids. It was theorized that these motion profiles could have a significant impact on screen blinding and therefore add further performance and efficiencies to an already successful design. Finally, the report documented the continuing work on a dry application for SmartScreens™ .

The ultimate goal of this project is to develop SmartScreens™ that will replace the inefficient massive electric motors. SmartScreens™ will have miniaturized, ceramic-based smart motors. SmartScreens™ will incorporate an energy management technique to control energy flow and will confine injected shaking energy to the screen panels. As part of the development efforts of SmartScreens™, a Steering Committee for Smart Screen Systems (SC-S3) was formed. Members of SC-S3 are QRDC (leading role), ARC (Albany Research Center, provide solutions that makes National's energy systems safe, efficient, and secure), U.S. Steel-MINNTAC (Minnesota ore operations), Ispat Inland Mining, S3i (Smart Screen System Inc.), and a representative of DOE-NETL. The QRDC team proposed to combine state-of-the-art smart materials, the concept of single or multi-stage resonators, and QRDC's recently patented energy management technique. This innovative technology has won several Research and Development awards from the U.S. Army, Navy, and Air Force and commercial organizations [2-4].

A miniaturized motor consumes 96% less energy than the bulky electrical motors and is capable of operating over a wide range of frequencies. These motors are almost maintenance free as they do not have any moving components and do not need lubrication. Piezoelectric ceramic material (Such as PMN= Lead Magnesium Niobate, and PZT=Lead Zirconate Titanate) can be miniaturized. Ceramic materials are well suited for applying large dynamic forces and the required shaking functions to resonators. In addition, ceramic materials will function as collocated sensors and actuators for active control of the shaking action and process automation. Cantilever resonators of appropriate shape and size will be used as resonators to amplify the displacements and accelerations so that the screening function is optimized. The combination of resonators and smart materials will offer full control and precision of the shaking function. Finally, the system will be optimized and completed by incorporating the energy management techniques that have been developed by QRDC. It is the combination of smart materials and the vibration energy managing method that makes the approach unique and innovative. Energy management is composed of energy diversion, confinement, dissipation, conversion, and cancellation.

The proposed technology offers significantly better energy management by controlling the flow of energy and confining it to screen panels rather than shaking the supporting frame, motor and surrounding structure. SmartScreens™ offers better control over the speed of operation, and type and magnitude of motion. These abilities help to quickly clean the screens and avoid blockage or blinding of screens. Use of miniaturized motors and by focused energy, SmartScreens™ eliminates and/or downsizes many of the structural components typically associated with industrial screens. As a result, the surface area of the screen increases for a given space envelope. This increase in usable screening surface area extends the life of the screens and reduces required maintenance. Energy management and better control of the screening process helps to remove particles of the correct size and thus increase the throughput, reduce material re-circulation, and significantly reduce in power consumption.

During the last two quarters, QRDC has focused on developing a successful magnet-driven seed cleaner, with an improved deblinding strategy.

This report summarizes the work since the last semi-annual report and has three main chapters. Chapter 1 explains the final design concept for the dry application seed cleaner that was fabricated during this reporting period, and includes discussion on a new deblinding concept. Chapter 2 summarizes the results obtained from lab testing with this prototype. Chapter 3 proposes some alternative approaches to the deblinding apparatus for seed screening. A summary of findings, results, and recommendations are found in Chapter 4.

EXECUTIVE SUMMARY

Two undesired components of the material processing industry are excessive consumption of energy and extreme noise and vibration. Current screening machines use an electrical motor with a rotating unbalanced mass to generate shaking. These motors not only generate motion in the screen panels but also shake the supporting structures and other machines and structure in a plant. During initial field investigation of existing screening machines, it was found that the existing vibrating screens are inefficient, noisy and waste significant amounts of energy. Many areas were identified that need either improvement or complete changeover. These areas include, material handling, screening process, screen blinding, moving mass, motion, energy consumption, noise levels and vibration transmission, and workers safely.

To address the above-mentioned issues, QRDC proposed an innovative concept, SmartScreens™ technology, based on smart materials (miniaturized motors), and Energy Confinement and Flow Control. This project is jointly funded by the DOE and industry partners that include representatives of the mining industry ISPAT INLAND MINING, U.S. Steel-MINNTAC (Minnesota ore operations), QRDC (a technology company with an extensive relevant track record), S3i (screen manufacturing company transferring the prototypes to full marketable and producible products), and the Albany Research Center (provide solutions that makes national energy systems safe, efficient, and secure). The key objective of this project is to demonstrate the feasibility of energy management-based SmartScreens™ that can efficiently handle and process material separation. SmartScreens™ have the capability to control the flow of energy and confine this energy to the screen itself rather than shaking the entire machine and the surrounding structure, which comprises conventional vibratory screening machines. Better control of energy flow results in better screen recovery and reduced re-circulating load of the slurry. Single or multi-stage resonators with an advanced sensory system will be used to continuously monitor screening processes to improve productivity. Smart material-based miniaturized motors offer better control over speed of operation, and the type/magnitude of motion. These abilities help to effectively clean the screens and avoid blockage or blinding of the screens. Miniaturized motors eliminate any moving components such as bearings and bulky unbalanced rotating mass. This, in turn, virtually eliminates noise. With the proposed SmartScreens™ technology, the weight of the moving mass can be reduced by as much as 80%, and thus results in significant reduction in energy usage.

In the development efforts of SmartScreens™, baseline data was obtained and an initial field investigation was completed to identify problem areas in the current fine screens. Based on this information, a plan was developed that identified the basic design requirements to improve and efficiently handle the screening process. Various conceptual designs were identified for the key components of the system. These key component designs (i.e., smart motor and motion amplifiers or resonators) were modeled in CAD programs and analyzed through computer simulation and experimental tests. Some of the key component designs were selected and a full system was modeled that included the screen panel, four resonators, miniaturized smart motors, and the supporting structure for resonators and screen panel. The performance of these key components and systems was analyzed under various loading conditions through finite element analysis and experimental tests. Based on these results, three systems were selected. After a detailed review, one or two of these key components and systems were fabricated as a prototype for the SmartScreen™.

During the past 2 quarters, QRDC finished fabrication and evaluation of a screening machine for the seed separating industry. This prototype demonstrated the ability of Smart Screens' core technology to extend across industries and may serve as a springboard for commercial applications of Smart Screens outside of the mining industry. Additionally, this prototype introduces a new approach for the blinding issue in dry application screening.

In the next reporting phase, QRDC intends to complete all testing of the dry-application prototype to evaluate its performance. This testing will include measurements on throughput, efficiency, and power consumption. As part of this performance evaluation, new deblinding concepts will be investigated and tested. The most promising deblinding approach will be fabricated and incorporated into the system. The goal of the deblinding mechanism will be for near-full deblinding at a reduced weight, power, and complexity. The goal for the overall system will be similar stroke and frequency with less power draw and equal or more throughput.

The SmartScreens™ technology with its capabilities to reduce current energy requirement, maintenance cost in screening operations, improve throughput, and reduce noise and vibrations levels, can impact the global process industries. The widespread application of the proposed technology could change the way material separation is handled in general processing industries. Candidate industries are oil and gas, mineral processing, food processing, and pharmaceutical applications.

CHAPTER 1 – SEED CLEANER DESIGN SPECIFICATIONS

In the 5th semi-annual report, the evaluation of a commercially available seed cleaning machine was discussed. The last semi-annual report outlined a set of design opportunities for the application of Smart Technologies in a grain screening prototype [11]. This chapter examines each of those design opportunities and illustrates how they were addressed in the most recent design of a laboratory seed cleaner prototype.

1.1 Overall Seed Cleaner Design

Multiple design goals were satisfied during this reporting period. Figure 1.1.1 illustrates the overall design of the system recently completed. This design incorporates a single-source drive approach, a novel system tuning device, a simple and compact solid frame, and the same shoe design that was proposed in the previous semi-annual report. An additional part of the design is a novel deblinding approach, which utilizes coil-springs and costs very little in terms of added mass.

1.2 Single Actuation Energy Source

In the previous semi-annual report, two actuation concepts for the seed cleaner were proposed: actuation of the overall shoe and actuation of the individual screens (for deblinding). The development plan for that report included two different actuation sources (magnets for the overall shoe actuation, and a different source – potentially PZTs – for the screen actuation). During this reporting period, QRDC has identified an option that addresses both actuation problems, while removing the extra weight and complexity of a metal ball deck, as is currently used in the field.

An electromagnet actuation method has been chosen to both move the shoe and activate a deblinding mechanism based on a coil-spring/mass system. As the shoe moves due to the forces imparted on it by the electromagnet, masses suspended by coil springs are energized enough to impact the individual screens. The design of this drive system is illustrated in figure 1.2.1.

A few key design concepts for the electromagnetic drive system should be noted. First, a drive of this kind prevents the need for any mechanical linkages between the shoe and the driving mechanism. This allows for the possibility of a drive failure or replacement without necessarily halting the system operation (for example, if another drive was still active). Secondly, the design developed incorporates a shimming technique that enables the user to easily move the magnet closer to and farther from the shoe without requiring addition or subtraction of material, as in the traditional approach to shimming. This same feature allows for the magnet to be set at an angle to the vertical, as would be helpful when more displacement is expected at one point than another (see figure 1.2.2). Additionally, the current design allows for movement of the magnet in a vertical direction. This is accomplished through a loop hole pattern on the units frame that attaches to the back-plate of the drive with bolts. Finally, the drive's adapter plate is suited for either a larger electromagnet or a smaller one, simply by using different hole patterns. These hole patterns could, of course, be customized to the hole pattern of any magnets that fit within the footprint of the adapter plate.

1.3 System Tuning Approach

The primary principle that allows this machine to work at such large energy savings is resonance. Resonance is based on the stiffness of the system as well as its weight. Since the weight of the shoe and its contents may change based on application, the stiffness should be alterable in case a relatively similar frequency would like to be maintained. Additionally, there may be times when a higher or lower frequency may want to be targeted. Therefore, a simple tuner was designed to allow for changes in the resonator effective length, which will change the stiffness of the system respectively. Figure 1.3.1 illustrates the concept. Analyses indicate that this simple mechanism can offer a frequency change span of 2-3 Hz.

1.4 The Frame

Figure 1.4.1 illustrates the frame design for this system. It is intended to be compact, rugged, simple, and functional. The cross-section of the steel piping is 2” x 2” x 1/8”, with gussets used where needed. The back end of the frame is left open for access to the back of the shoe, as is the top of the frame. Mounting pads with appropriately tapped holes are welded where the resonators are to be held. Additionally, the plates required for the magnetic drive system installation are included as a permanent weldment.

1.5 The Shoe

Figure 1.5.1 illustrates the shoe design. This is the same design that was introduced in the last semi-annual report. This design is very similar to that used by an industry leader in seed separation.

1.6 A New Approach To Deblinding

Blinding is a constant problem in the seed cleaning industry, due to the tight tolerances required for the products. A number of approaches to deblinding of screens have been in use for years, but most add significant weight, complexity, or required energy to the system. QRDC has recently been working on a new concept that should minimize all three of these setbacks. Figure 1.6.1 shows a diagram that depicts the basic principle. Underneath the screens is a tray that collects the undersized seed. On that tray can be placed a coil spring with a ball mass attached to it. As the shoe moves horizontally, the momentum of the mass moves it out of the neutral position. As the motion of the shoe changes direction (as it does about five times per second) the mass will be drawn back by the spring, until it impacts the screen to halt it. Key design variables include: stiffness of the spring, length of the spring, mass of the ball, and locations of the devices within the shoe.

CHAPTER 2 – THE FABRICATED DRY-APPLICATION UNIT

Fabrication of the dry-application cleaner was completed during this reporting period, with very promising preliminary results. Figure 2.1 shows a photograph of the system taken at QRDC's facility. A feeding mechanism to help dispense the seed at a 600-700 lb/hr rate was also added during this reporting period. The seed used for testing wheat.

2.1 Frequency Calibration

The first verification after assembly was complete was of the operating frequency (natural frequency) of the system with and without seed. It was found that with the resonator tuners placed in their lowest position (highest frequency) the natural frequency without seed is about 5.25Hz. When incorporating the seed at 600-700 lb/hr, the added weight brings the frequency down to 5.15Hz. This agrees very well with analytical models of the system, which predicted frequencies between 5 and 7 Hz. Lower frequencies can be reached if the resonator tuners are adjusted appropriately. It should be noted that the fastening torque used is very significant in the operating frequency outcome. Investigations into the exact torques needed are still underway.

2.2 Horizontal Stroke Achievements

Once the frequency of the system was verified, it was necessary to discover whether the required stroke of $1"_{pk\text{-}pk}$ could be readily achieved. It was found that, even with the 600 lb/hr seed flow, as much as $1.25"_{pk\text{-}pk}$ horizontal displacement could be realized with very little power draw by the magnetic motor controller.

Rotation of the shoe has also been checked by monitoring the horizontal displacement at two corners of the shoe. Based on these results, it is safe to say that any rotation (if it exists) is very minor, and was certainly not detected with the displacement sensors used for our testing (LVDTs).

2.3 Power Measurements

As was mentioned above, the power required to keep the system running was very low. Exact calculations on the power savings of this unit when compared to other units in the field will be made in the near future. An added benefit, however, is that the system seems to be fully operational with only one electromagnet. That is to say that, if one of the two magnets were to stop operating, the other could keep the unit running at the same 1" stroke, at the same frequency, and with a similar power draw. This could be a serious improvement over the current systems in the field that operate with a linked rotary system that must be halted and kept off-line in the event of a motor failure.

2.4 Deblinding Results

The deblinding results we have received so far are very promising. Optimization of location, spring selection, and ball mass is still under way. Other ideas are still being proposed and investigated as well. However, as of this report, QRDC is seeing deblinding improvement on the order of 50% (compared to no deblinding apparatus whatsoever). Figure 2.4.1 shows photographs of a screen before and after the coil-spring deblinders were introduced. It should be noted that all results are still preliminary and subject to further, more thorough testing.

2.5 Future Testing Plans

A number of tests are scheduled to be completed during the next reporting period. They include:

1) Fastener Torque Testing
2) Power Consumption Measurements
3) Efficiency Measurements
4) Deblinding Optimization

Additional experiments may also be conducted, especially in the event of different deblinding ideas.

CHAPTER 3 – FUTURE APPROACHES TO DEBLINDING

While QRDC's current system performs very well in comparison to other commercial seed cleaners, the hurdle of a fully effective deblinding mechanism still exists. Aiming for near-100% deblinding capabilities, QRDC's team has been investigating alternative approaches to the blinding problem. This chapter aims to identify a few of the most promising ideas, which will be evaluated in more depth during the next reporting period.

3.1 Bungee Net Deck

Currently in the field, a metal "ball deck" is often used to hold deblinding balls. This ball deck acts as a mechanical device to impart vertical energy into rubber balls that impact the screens. This deck is heavy and takes up a significant amount of space. QRDC has initiated an internal investigation into replacing this metal deck with something much less intrusive, such as a net made out of an elastic material. This net would allow balls to bounce around, as they do in a traditional ball deck, without the added weight and size. It would be easy to remove and replace. An added feature may be the attachment of the balls to the net, which would remove the need for any dividers that add even more weight to the system and at the same time, hamper deblinding mechanism to be effective along the line of dividers.

3.2 Rubber Rod Approach

Along the same lines of the coil-spring approach, a rubber rod which allows for axial movement could harness the horizontal energy and transfer it into vertical energy without the possibility of permanent deformation that coil springs may have. This mono-filament material could potentially be connected to thin beams that span the width of the shoe, or could be mounted on the seed collection tray as are the coil springs.

3.3 Screen Brushing

The use of a brush that dislodges stuck seed is not new. However, incorporating resonance may give this approach an added edge, removing any need for an additional controller to keep the brushes moving. The use of a brush-type mechanism could decrease the amount of energy lost to the balls in a classical deblinding strategy, while cleaning screens more consistently and predictably (the process would not be at all random).

3.4 Tuned Leaf Spring

One of QRDC's original deblinding concepts included a leaf spring that impacted the screen from underneath, much like the coil-spring approach. However, the stroke and force of these leaf springs were not brought to satisfactory levels in preliminary testing. Additionally, these designs all incorporated an added actuation source, such as a PZT. A leaf spring tuned to the frequency of the system and placed at an angle could be just the thing to solve both of these problems, however. By tuning it to the resonant frequency of the system, the additional actuator could be removed. Placing the spring at an angle could allow the horizontal motion of the shoe to transfer into the impacting tip, sending it back in the vertical direction. One potential drawback to this approach is the impact location on the screen, which would, in the current vision of this strategy, always be at the same point.

CHAPTER 4 – CONCLUSION

In this report, our progress since the last semi-annual report was detailed. The work done has focused on the dry-application screening prototype which has been fabricated and tested to an extent at QRDC's Chaska lab. Results are very promising, and show that basic design and finite element analyses were well-based. Particular successes include an industry-comparable shoe, a compact and functional frame, a tunable system with a new drive system, a reduction in power consumption, and a new deblinding technique. Challenges ahead mainly pertain to improvements in the deblinding approach, as well as more thorough testing of preliminary results.

In summary, this project is progressing at a healthy rate and is continuing to meet goals and expectations.

FIGURES

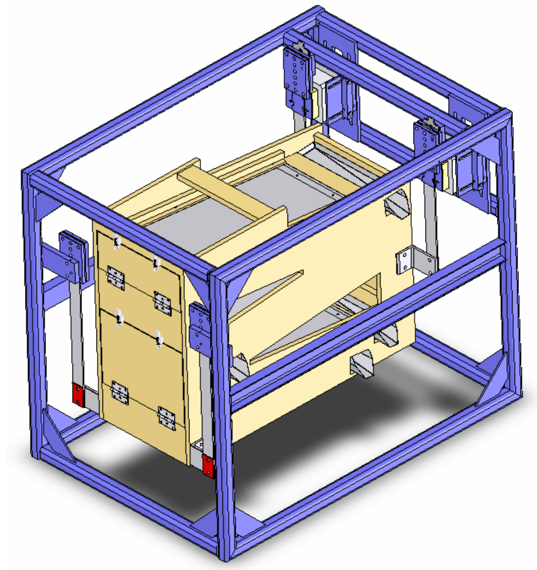

Figure 1.1.1 CAD depiction of entire seed cleaning system lab prototype

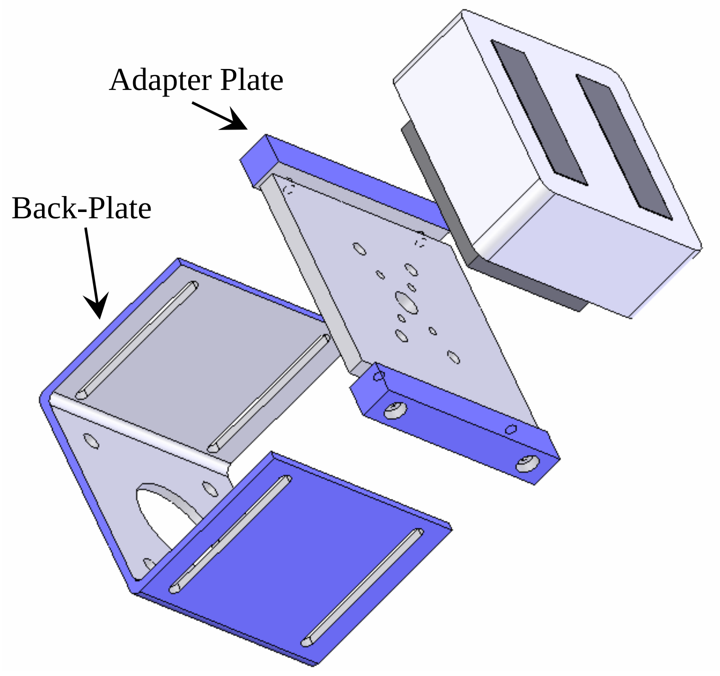

Figure 1.2.1 Electromagnet drive system design

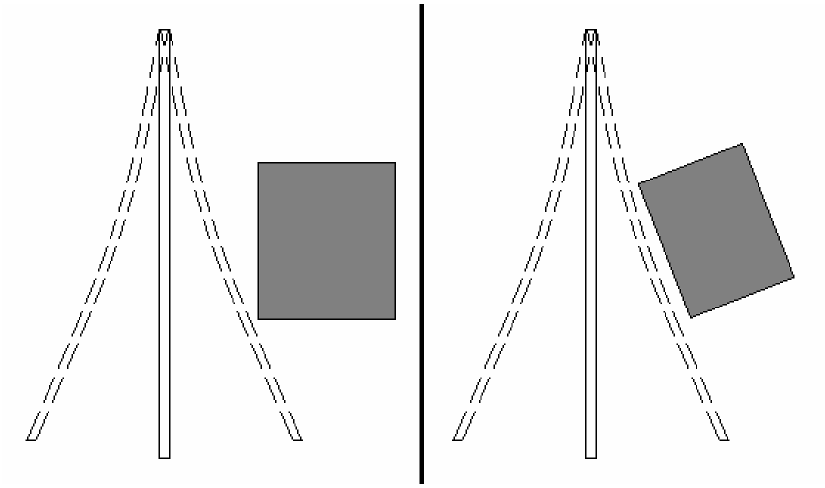

Figure 1.2.2 Benefit of angled magnet

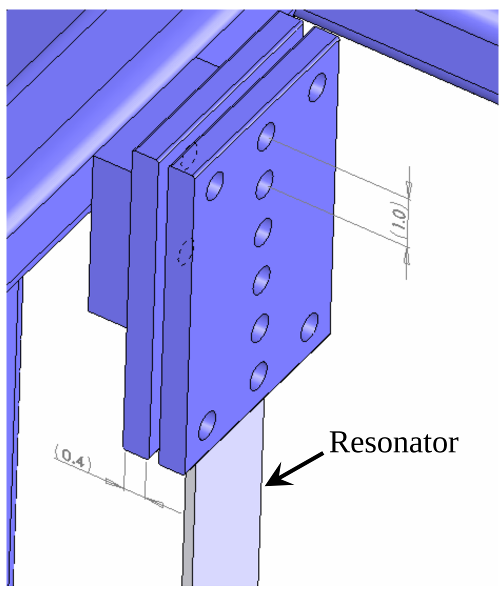

Figure 1.3.1 System tuning aparatus

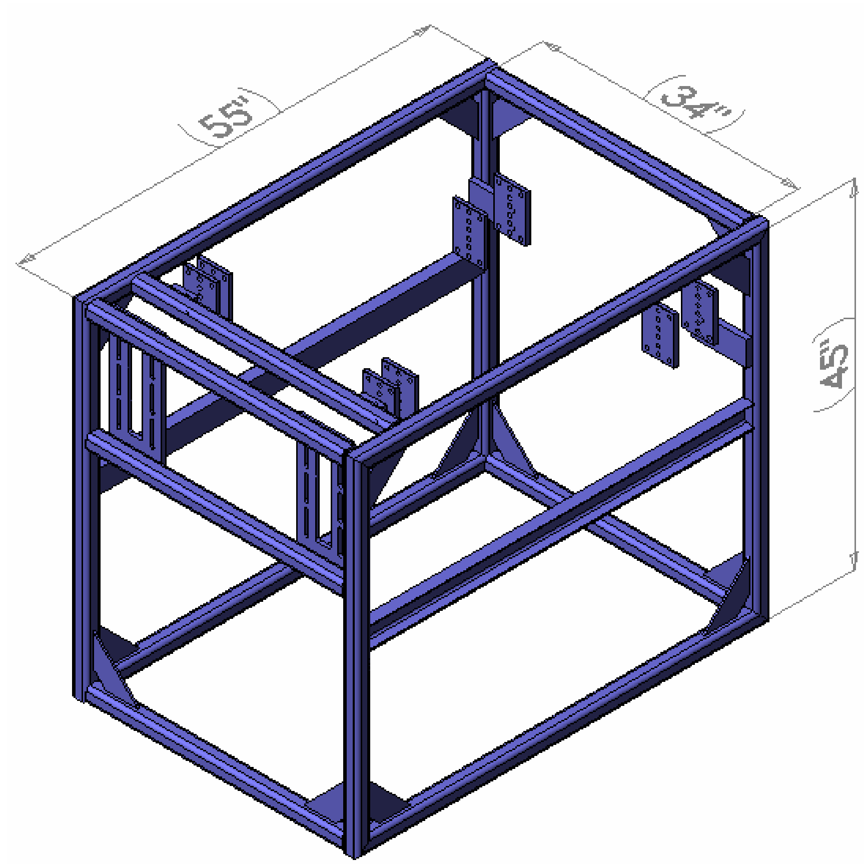

Figure 1.4.1 System frame design

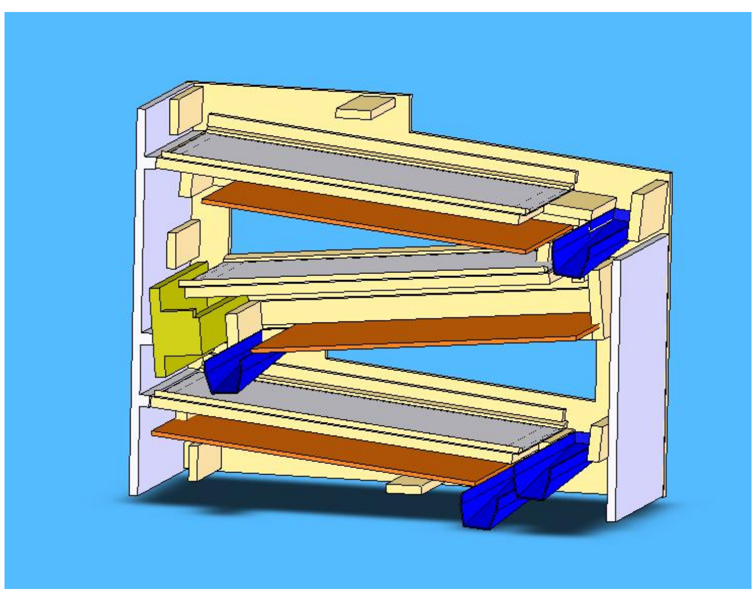

Figure 1.5.1 Cutaway of shoe design

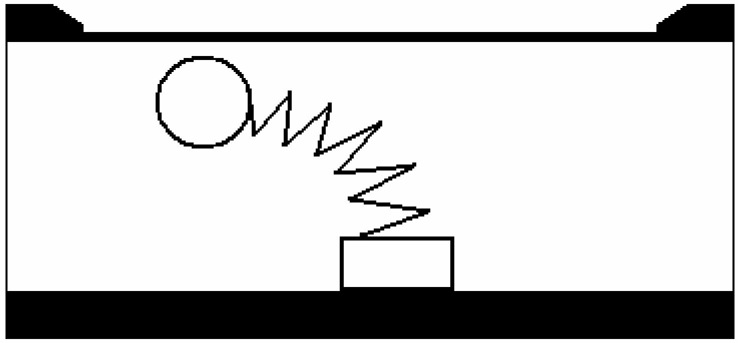

Figure 1.6.1 Spring-Mass deblinding concept

Figure 2.1 Fabricated seed-cleaner prototype

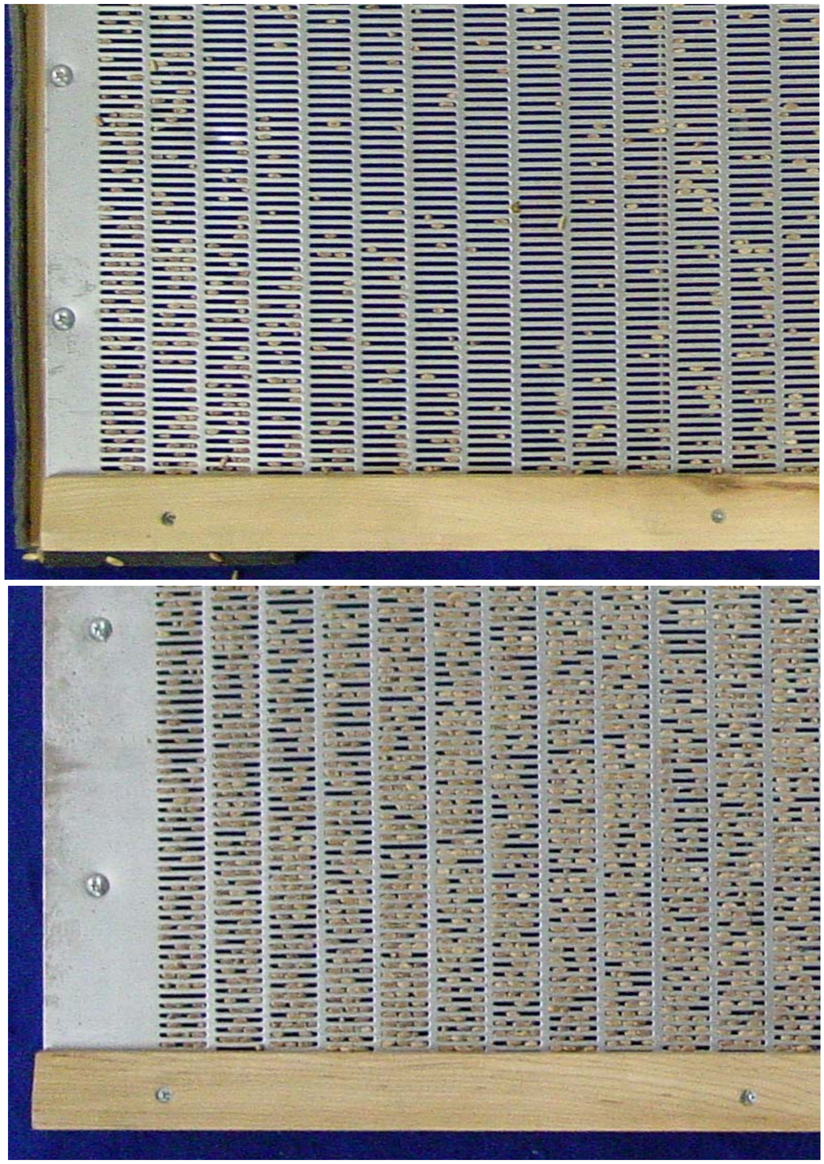

Figure 2.4.1 Comparison of screen with spring-deblinders (top) and without any deblinding mechanism (bottom)

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LIST OF ABBREVIATIONS

S3 – Smart Screen Systems
ARC – Albany Research Center
SM – Smart Motor
SC-S3 – Steering Committee for Smart Screen Systems
PZT – Lead Zirconate Titanate
PMN – Lead Magnesium Niobate
CAD – Computer Aided Design
FEM – Finite Element Analysis
OMS – Operating Mode Shapes
MSHA – Mine Safety and Health Administration's
PLC – Programmable Logic Controller
SPL – Sound Pressure Level
OM – Oscillating Mass
LD – Live Deck
OMR – Oscillating Mass Resonator
CMRL – Coleraine Mineral Research Laboratory, part of The University of Minnesota
IIM – Ispat Inland Mining
SSL-PZT – Solid Leg Frame Suspend with Coil Springs, Powered with PZT Stacks