Quality Research, Development, and Consulting Inc.

Smart Screening System (S3)

In Taconite Processing

Semi Annual Report

Report Start Date: Mar. 9, 2003

Report End Date: Sept. 8, 2003

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Report Issued Date: April 2004

DOE Award # DE-FC26-02NT41470

Smart Screening System (S3) In Taconite Processing

Semi Annual Report

This report is prepared for

Department Of Energy (DOE) & Partners
(Partners include: Albany Research Center, ISPAT Inland Mining,
U.S. Steel-Minntac, and S3i)

DOE Award # DE-FC26-02NT41470
Report Issued Date: April 2004

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ACKNOWLEDGMENT

This Semi-Annual report titled “Smart Screening System (S3) In Taconite Processing” was prepared with the support of the U.S. Department of Energy, under Award No. DE-FC26-02NT41470. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the DOE.

ABSTRACT

The conventional vibrating 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 most every processing plant. Most of the current material separation technology uses heavy and inefficient electric motors with an unbalance rotating mass to generate the shaking. In addition to being excessively noisy, inefficient, 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 structure 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 conceptual designs for key components of the SmartScreens™ have been developed. These key components include: smart motors and resonators. It is shown that the smart motors have a good life and performance. The resonators are utilized to amplify motion generated by smart motors. Resonator designs are selected based on the final system requirement and vibration characteristics. In addition, a tabletop demo unit was developed and demonstrated during a conference in 2003. This demo is reviewed in this report. The concept has shown promise and the program is on schedule.

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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 to 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 [2-4].

In the previous reporting period, it was shown through computer simulations that smart motors, accompanied by specially designed resonators, could 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, 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 was the combination of smart materials and these vibration energy managing methods that made this approach unique and innovative.

In this reporting period, 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 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

increase 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 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 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 on the screening process helps to remove particles of the correct size and thus increases the throughput, reduces material re-circulation and significant reduction in power consumption.

During last two quarters, we have focused on the design, development, fabrication, testing, and evaluation of the key components of the proposed smart screen systems. These key components are smart motors and resonators that are used as motion amplifier. In

addition, a tabletop demo was developed and fabricated. The demo unit was displayed in the DOE-sponsored conference in Nevada.

During this period of work conceptual designs for resonators are developed. After experimental testing and computer-based analysis, resonator designs are down selected based on the system requirement and vibration characteristics. The most promising resonator designs are incorporated into the model and the full system analyzed.

This report summarizes the work since the last semi-annual report (Quarter 2-2003 & Quarter 3-2003) and has three main chapters. Chapter 1 is directed towards component development and fabrication. Chapter 2 gives details on the test results and evaluation of these components. A summary of findings, results, and recommendations are found in Chapter 3. Appendix A contains proprietary information and is referenced in the main body of the report.

EXECUTIVE SUMMARY

Two undesired component 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 on 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 worker safety.

To address the above-mentioned issues, QRDC proposed an innovative concept, SmartScreensTM 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 SmartScreensTM that can efficiently handle and process material separation. SmartScreensTM have the capabilities to control the flow of energy and confine this energy to the screen itself rather than shaking the entire machine and the surrounding structure that comprise the conventional vibratory screening machine. Better control on energy flow means 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 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 like bearings and bulky unbalance rotating mass. This in turn virtually eliminates noise. With the proposed SmartScreensTM 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 SmartScreensTM, baseline data was obtained and 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 requirement 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 experiment tests. Based on these results, three

systems were selected. After a detailed review, one or two of these key components and systems will be used in the development of SmartScreensTM.

The SmartScreensTM 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 – EXPERIMENTAL

Three main components of S3I's SmartScreen™ designs were designed, refined and analyzed for performance improvements during this reporting period. These components were: the smart motor, the resonator, and the supporting structure. Each component had the flexibility to be modeled and analyzed regardless of whether the other two components had been refined or not. This allowed for parallel design efforts that did not interfere with one another. What follows in this chapter are descriptions of what steps were taken in the design refinements, and what analyses were performed before fabrication was to take place.

1.1 Smart Motor

Two ceramic-based smart motor designs were developed and fabricated by the QRDC team. An overview of these designs is presented in this section. A detailed description of the designs is presented in Appendix A.

While some of the details of these innovative designs have been discussed in our status reports, it is important to recall the characteristics that both designs share, as well as the differences that make one design more adequate for the SmartScreen™ application. Both motor assemblies share the same basic components. The piezoelectric (PZT) ceramic is one of the key components of the motor. The PZT element expands and contracts with an increase and decrease in voltage, respectively. These PZT actuators are made of Lead Zirconate Titanate (PZT) and are small discs stacked on top of one another, as shown in Figure 1.1.1. PZT actuators have unique features. 1) They expand when an electrical potential (voltage) is placed over the top and bottom opposing surfaces shown in Figure 1.1.1. 2) They can provide a tremendous amount of force from a relatively small amount of voltage. 3) Their reactions are near instantaneous to their voltage inputs. These three attributes make them very attractive for the smart motor designs, which require large forces with small power requirements and good frequency control.

There are a few challenges that need to be addressed when PZT actuators are used in this application. First, the displacement output (stroke) of a PZT actuator, when subjected to an electrical potential, is small enough that is expressed in microns. Second, ceramic-based actuators are brittle and easy to fracture. These two challenges are the main reasons that additional smart motor components are required in the overall assemblage of the motor. Mechanical amplifiers or resonators serve the purpose of amplifying the PZT stroke. The force transfer component serves as the main device to connect the resonator to the PZT actuator, and thereby excites a system mode that will transfer energy more efficiently to the screen panel. Since shear loads and friction are detrimental to the ceramic and limit system performance, uniform loading and minimal friction losses are required. Also, since the ceramic applies force only in the extension direction, preload and restoring components are needed. Additional details on these motor components are included in Appendix A, section A.1.

In addition to the above-mentioned components, the more recent smart motor design, shown in Figure 1.1.2, includes three important design parameters. 1) It offers an easy ceramic installation and requires no glue as in previous designs. 2) Only one preload is

required. Other designs required two preloads required. 3) Larger holes are incorporated for wires. For these three reasons, the most recent design has been selected for use in the SmartScreens™. This design is detailed in Appendix A.

1.2 Resonators

Resonators (or motion amplifiers) are another key component of the screening system. A resonator is designed to have two functions. First, it amplifies the displacement of a smart motor at a designed frequency that matches the operating speed of the machine. Second, it creates a vibratory motion that pushes particles in both the vertical and flow directions. In the first semi-annual report submitted by QRDC, many resonator design examples were put forward and analyzed. For this reporting period, the resonator design depicted in Figure 1.2.1 was used. This resonator design is comprised of two curved beams and it is referred to as split beam resonator. The split beam concept generates acceptable stress levels when subjected to excitation.

While the details of this design are reported in quarterly reports, it is important to note a few benefits of this design. The first benefit is that the resonator is “split” lengthwise. This split is important because it reduces stress levels, as seen in Figure 1.2.2. The desired resonant frequency (running speed) is maintained. The only negative effect of a split resonator was a drop in peak performance of about 3%, which was deemed acceptable when compared with the stress reduction benefits.

1.3 Oscillating Mass Design

Another design approach, the oscillating mass design, was considered during this reporting period. The approach is based on the idea that single or multiple oscillating masses could be actively excited at their natural frequencies (similar to the resonator designs), and the resonators underneath the live deck can be passive and part of the supporting structure. The details of the designs investigated in this reporting period are presented in Appendix A, section A.2.

1.4 The Supporting Structure

While smart motor and resonator designs were essentially completed, the supporting structure for the SmartScreens™ had significant room for improvement. The QRDC engineers focused on a design that utilized “tubular” beams, as seen in Figure 1.4.1. This design adds support to the edges of the beams, reducing vibration levels and thus improving vibration containment. Simulated displacement results of the screen’s surface (live deck) are shown for each case in Figure 1.4.2. The higher displacement at resonance for the tubular structure is compared to the original I-frame supports. It is observed that the maximum displacement is increased by about 75%. This anticipated increase in performance was the key reason for the use of tubular beams in the supporting structure.

An additional change to the supporting structure was the inclusion of rubber pads to the mounting plates of the supports resting on the floor. This design alteration was based on the belief that lowering the supporting structures natural frequencies would actually introduce *another* mode near the target frequency (the frequency at which the screen is actually excited) that might produce higher displacements. However, simulated analyses were not promising, as shown in Figure 1.4.3 for the tubular structure. Similar results were obtained for I-frame supports.

One of the more significant changes made to the supporting structure design involved completely removing the static plate shown in Figure 1.4.4. The initial purpose of the static plate was to allow for a connection interface between the vertical supporting legs and the resonator/motor assemblies. However, it was identified that this static plate introduces a number of issues and challenges as listed below.

- 1) **Vibratory Energy Transmission to the Supporting Structure:** The resonators are mounted on the static plate, which in turn is mounted on relatively soft supporting structure, allowing vibration transmission to the legs and base.
- 2) **Static Plate Bending:** Due to its own weight and the soft supporting structure, the static plate has bending characteristics that add to the vibrations of the system. These excess vibrations are undesirable and could be detrimental to the life of resonators.
- 3) **Energy Loss through Extra Bolt Requirement:** Possibly the biggest issues is the 40 plus bolts required between the live deck and the supporting structure. As a result, the presence of the static plate negatively influences system performance, installation time, and maintenance cost.

It was because of these reasons that a new support design, with no static plate, was developed. This design is shown in Figure 1.4.4. It should be noted that the number of nuts and bolts used in each design are substantially different. In the design with a static plate, approximately 100 nuts and bolts were used. With the newer design, shown in Figure 1.4.4, the number of bolts is cut in half due to removal of the static plate. Welding the legs to the base further reduced the number of bolts to around 25% of the other design. Additional bolts add not only time and effort to assembly, but are also large sources for vibration and energy loss that could otherwise be used to excite the live deck.

CHAPTER 2 – RESULTS AND DISCUSSION

In this chapter, a summary of the numerical and test results on the key components are presented. Issues, challenges, and recommended improvements are discussed. A brief discussion on the selection of materials required for the working prototype and the electrical equipment needed for controlling the PZT-based smart motor is also presented.

2.1 PZT-based Smart Motor Evaluation

The PZT-based smart motor was used for performance evaluation over a long period. The test article is shown in Figure 2.1.1. The motor assembly was inserted into the test fixture; the curved resonator was installed between the base block and a 40-lb mass attached on top of the resonator, and the entire test article was bolted to the floor. The top mass is equivalent to $\frac{1}{4}$ of the total weight of a typical live deck. The system was set up with a circular stacked PZT actuator and the system was preloaded. The system was tuned to its first resonant frequency and allowed to run to failure. The driving frequency was set to 16.7 Hz with an applied voltage of 0-87V (with D.C. offset). The resultant motion was 90 mils p-p in the vertical direction measured directly on the resonator tip. A schematic view of the test article is shown in Figure A.3.1. Additional configuration information is provided in Appendix A, section A.3.

To avoid any possible arcing between the ceramic and the surrounding metal parts, the ceramic was first coated with liquid electrical tape and completely covered with black plastic electrical tape. Thus, only the inactive ceramic faces were exposed. Room temperature between 74-78°F was maintained through out the test.

The test article was set to run round the clock for almost one month before failure. The test was started on June 16, 2003 and failed sometime before July 14, 2003. Before disassembling the system, all the electronics, connections, and wires were checked and no problems were observed. On further investigation, it was clear that the ceramic had failed. When all the parts were disassembled, it became apparent that there was an electrically generated fire. After removing electrical insulation, it was found that the positive wire was disconnected and some ceramic material was lost around the positive wire connection area. Figure 2.1.3 shows the failed ceramic actuators and motor parts.

Table 2.1.1 shows sample data collected during the longevity test. The laboratory system was set up with a 38 mm circular ceramic in the 28 mm core assembly and preloaded. The assembly was then inserted into the test fixture, the curved resonator was attached, and a 40 lb mass was attached to the resonator. Torque was then applied to the fixture bolt to complete the pre-load process. The system was tuned to its first resonant frequency and allowed to run until failure. The frequency was set to 16.7 Hz with an applied voltage of 87V. The resultant motion (stroke) was 91.41 mils measured directly on the resonator tip in the vertical direction. The same measurement was made at each hour for the first day, with no drop in performance. Over the next two days, this measurement was made every four hours, with the system still maintaining 90.27 mils stroke at the end of the third day. Upon taking a measurement the morning of the fourth day, it was realized that the motion had reduced to less than 90 mils, so the system was re-tuned. The frequency was changed to 16.6 Hz with the voltage kept constant, and the motion increased to 105 mils stroke. The motion

was still over 98 mils at the end of the working week, so the system was allowed to continue to run at 16.6 Hz and 87V. Upon measuring the system in the first day of the next week, the eighth day of operation, the frequency had again shifted; the motion was about 91 mils. The system was re-tuned to 16.55 Hz, and the motion increased to 119 mils. The system continued running until either the resonator or the ceramic elements failed.

Table 2.1.1 Measured data over 3 weeks of time

Date	Time	Frequency (Hz)	Vertical Stroke (mils)	Voltage (V)
06/16/03	11:00	16.70	91	86
06/16/03	12:00	16.70	98	86
06/16/03	13:00	16.70	98	86
06/16/03	14:00	16.70	97	86
06/16/03	15:00	16.70	98	86
06/16/03	16:00	16.70	98	86
06/16/03	17:00	16.70	98	87
06/17/03	8:00	16.70	91	87
06/17/03	15:30	16.70	90	87
06/17/03	14:30	16.70	90	87
06/18/03	11:00	16.60	105	87
06/23/03	12:00	16.55	119	87
06/24/03	8:00	16.55	113	87
06/26/03	9:00	16.55	111	87
07/01/03	9:20	16.52	6*	91
07/01/03	9:50	16.91	86	95
07/08/03	11:00	16.86	118	94

* Top bolt used to mount 40-lb mass sheared off

2.2 Evaluation of Oscillating Mass

In this section, the results generated by computer model and test results collected under laboratory conditions are presented. The system under consideration is shown in Figure A.4.1. Figures 2.2.1 and 2.2.2 show the key results for forced vibration analysis for the 8-DOF model. The results indicate that tuning the live deck and Oscillating Mass (OM) resonator to the same frequency will give the best displacement ratio between live deck and OM. In the latter case, the ration of 1 to 2 was realized. The ratio increases to 1:10 with live deck (LD) tuned to 5 Hz and OM to 60 Hz. As seen in Figure 2.2.1, a minimum frequency ratio of 1:1.25 between LD and OM is required to achieve target displacement ratio of 1 to 4.

Figure 2.2.2 shows the displacement ratio versus the mass ratio. It was shown that the displacement ratio between LD and OM was significantly influenced by mass ratio. In this figure, the frequency ratio was constant at 1.25. Since the best case was not practical and the curve was non-linear, a mass ratio of 5 to 1 was selected as the baseline for full system analysis.

Based on the above discuss results, full system and oscillating mass were separately tuned and analyzed. Forced analysis resulted in low LD displacement (below 20 mils stroke). Various different cases were analyzed by changing the mounting location of the OM. The mode of interest was when LD and OM are out of phase. However the force analysis

resulted in low LD and OM displacements. On further investigation, it was found that due to input force location, the moment arm was too long. The optimum case was realized when the input force was applied directly on mass. It was determined that, due to input force location, the results of the 8-DOF model did not agree with the full system analysis in terms of displacement ratio. Adding another DOF between LD and OM resonator could have resolved this issue.

Since the required forces cannot be applied on mass due to stroke limitations of PZT actuators, various designs were considered to increase end mass motion. A series of analysis was conducted by changing the end mass and stiffness of the resonator. Resonator length and thickness were adjusted in order to obtain the required stiffness. In the best case, detailed in Appendix A, section A.3, a vertical stroke of about 34 mils and horizontal stroke of about 8 mils were obtained. These results are shown in Figure 2.2.3. Further analysis revealed that the passive resonators (four supporting springs) go into higher mode bending. The lowest three modes of the supporting springs are displayed in Figure 2.2.4. Mode 5 is the target mode that is out-of-phase with respect to the Oscillating Mass (see Figure 2.2.4b). This mode 5 requires more force to excite due to its complex bending shape and deformation at two different curvatures.

To further understand the influence of forcing direction, a simple resonator was analyzed with dynamic forces applied in vertical and horizontal direction consecutively. The table below gives forced analysis results with the ratio between vertical and horizontal motion.

Table 2.2.1 Stroke Performance for two different forcing directions

Mode	Force applied along flow direction	Force applied in vertical direction
	Displacement Ratio - vertical/flow motion	Displacement Ratio - vertical/flow motion
Mode 1	1.5 to 1	1.5 to 1
Mode 3	3 to 1	3 to 1
Mode 5	4 to 1	9 to 1

Based on the above results, the optimum orientation of the OM with respect to the live deck (LD) was set. The resulting motion was almost equal in both directions, as shown in Figure 2.2.5. The vertical stroke drops to 22 mils from 34 mils. However the vertical and horizontal resultant motion remains the same for both cases. The resultant motion is parallel to the line of action.

In order to realize the required strokes, the OM design needs improvement. The good news is that the OM-based smart screen system is not sensitive to the boundary conditions and plant supporting structure. In the future work, the following can be explored.

- 1) Design a set of resonators that can be excited in its first bending mode is the out-of-phase mode. This design will achieve the target motion.
- 2) Optimize the total system dynamics.
- 3) Optimize the location of PZT actuator so that the reaction force is applied somewhere else rather than to the LD.
- 4) Explore the use of electromagnetic motors.

CHAPTER 3 - CONCLUSION

In this report, our progress since the last semi-annual report was detailed. It was shown that our progress has been satisfactory and the program is on schedule.

The design and evaluation of the key components were presented in this report. Various designs of PZT-based smart motors were presented. An alternative excitation method, based on an oscillating mass, was explored. Finally, a new design for the supporting structure was reported.

Two main areas were identified in the smart screening technology. These areas are listed below.

Shaking mechanism: Bulky electrical motors with bearings and rotating unbalance mass generates shaking. These moving parts are the main source of excessive noise and vibration, heat and higher maintenance costs. Our smart motors can replace the conventional, inefficient motors.

Technology limitation: Current screens have limited flexibility on frequency of shaking, type of shaking, orientation of shaking, and magnitude of input force. These factors affect the material separation process and lead to screen blinding. Smart screen approach must continue addressing these issues.

SmartScreens[™] technology offers solutions to the above problems. Through this technology, the energy flow and the motion of the screen are controlled more efficiently and effectively. Use of miniaturized motors offered greater flexibility to control speed of operation, type of motion and its magnitude, and noise free operation. S3 eliminates and/or downsized many of the structural components. As a result, the surface area of the screen increased for a given space envelope.

During this project period, conceptual resonator designs were developed for the proposed SmartScreens[™]. These resonators were analyzed and tested for performance. Based on the results, resonators were down selected and incorporated in the full system. Full system includes, screen panel, live deck and sub-assemblies. Three systems were down-selected based on the overall system requirements and vibration characteristics. After detailed review, one or two of these resonator systems will be used in development of SmartScreens[™].

By the time of the next progress report, fabrication, development and evaluation of S3 should be well underway. Next report will include chapters on materials and parts selection, prototype fabrication and evaluation, fabrication and development of S3 and field trials and analysis.

FIGURES

Figure 1.1.1 Diagram of circular PZT stack

Figure 1.2.1 – Design of the current split resonator composed of two curved beams

Flat curve resonator, stress distribution

(a)

Split beam resonator; stress distribution

(b)

Figure 1.2.2 Stress distribution of (a) single flat curve resonator and (b) split beam resonator

Figure 1.4.1 – Tubular Supporting Structure Design

Figure 1.4.2 Live deck displacements for I-frame structure (left)
versus tubular structure (right)

Figure 1.4.3 Live deck displacement for tubular structure on (left)
hard foundation and (right) soft foundation (rubber pads)

Figure 1.4.4 Supporting structure design without static plate

Figure 2.1.1 Laboratory setup includes a curved resonator, ceramic-based smart motor, mounting block, 40-lbs mass

Figure 2.1.2 Failed PZT-based motor parts

Figure 2.2.1 Displacement ratio versus frequency ratio (OM over LD)

Figure 2.2.2 Displacement ratio (OM/LD) versus mass ratio (LD/OM)

Figure 2.2.3 Displacement of the mass and live deck (LD) in vertical (top, a) and horizontal (bottom, b) directions, OM oriented at 0° degree with respect to LD as shown above

Figure 2.2.4(a) Lowest bending modes of a passive curved supporting resonator

Figure 2.2.4(b) Lowest three bending modes of an OM with a passive curved resonator integrated in a full system; for clarity only resonators are shown here

Figure 2.2.5 Displacement of the mass and live deck (LD) in vertical (top, a) and horizontal (bottom, b) directions, OM oriented at an angle with respect to LD as shown above

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LIST OF ACRONYMS AND ABBREVIATIONS

S3 – Smart Screen Systems
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