Fine Screening Machines That Use Smart Materials and Controls

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Figure 1: The first Single-Screen Smart Screen

The objective of this product is to address the specific need for improvements in the efficiency and effectiveness in physical separation technologies in the high-frequency fine-screening area. Currently, the mining industry uses approximately 33 billion kW-hr per year, costing $1.65 billion at $0.05 per kW-hr, of electrical energy for physical separation of mineral particles. Even though screening and size separations are not the single most energy intensive process in the mining industry, they are often the major bottleneck in the whole process. Improvements to this area offer tremendous potential in both energy savings and production efficiency improvements. Additionally, the conventional vibrating screens used in the mining processing plants are costly, from a maintenance and worker health and safety point of view. The goal of this product is to reduce energy use in the high-frequency screening process and in the processing as a whole. This goal has been accomplished by developing an innovative screening machine that employs smart motors and uses an advanced sensory system to continuously monitor the screening process and make appropriate adjustments to maintain optimum screening performance under varying loads.

The development of Smart Screen technology is based on two key technologies, namely smart actuators and smart Energy Flow Control™ (EFC™), originally developed for military applications. Smart Screen technology controls the flow of vibration energy and confines it to the screen rather than shaking much of the larger mass that makes up the conventional vibratory screening machine. Consequently, Smart Screens eliminate or downsize many of the structural components associated with conventional vibratory screening machines. As a result, the surface area of the screen increases for a given plant area "footprint".

Introduction

Conventional screening machines have one thing in common. They all use an electrical motor with a rotating eccentric shaft that generates the shaking. These rotary electric motor and shaft assemblies are bulky and require maintenance. Furthermore, much of the energy they require is wasted due to useless elastic deformation of the heavy equipment support structure and in the generation of excess noise and excess heat. The excess vibration and heat shortens the useful life of moving components such as bearings — creating excess parts and maintenance cost for a processing plant.

A conventional material screening machine is comprised of four primary and four secondary parts. The primary parts include the key moving components, such as engine, live deck, screen panels, and the screen panel tensioning mechanism. The secondary parts include the non-moving components, such as feed system, supporting structure, hopper, and oversize bins. An electrical engine provides the required shaking by using an eccentric rotating shaft. Typically, an engine rests on the live deck on which a screen panel tensioning mechanism is installed. The screens, that do the material separation, are supported by the tensioning mechanism. The live deck is usually mounted on a main supporting structure at four points using an air- or rubber-based isolation system. The isolation systems are designed to prevent transmission of excess vibrations to the main supporting floor and other parts of a plant. A feed system delivers material at a prescribed flow speed using conveyor belts, gravity feeds and/or pumps. The undersized particles flow into a hopper while the larger particles flow into the oversized bins. The larger particles will be recycled and eventually will be collected as waste.

These types of screening machines have high maintenance cost, downtime, and excessive noise levels. In addition, they have a low productivity rate and a negative impact on workers health and safety. The main issue is that too much heavy metallic parts are shaken for a relatively small payload. Typical engines may weigh about 5 times the screened materials or payload. These engines generate high levels of noise and heat. In addition, they are high maintenance and consume too much energy for generating the required shaking force. An eccentric rotating mass in an engine generates the required oscillatory forces. Since the engine is hard mounted to the live deck, a relatively large steel structure, its vibrations cause the live deck to shake. A typical live deck weighs about 16 times the payload. The shaking of this large steel structure not only generates structural-borne noise but also generates high cycle fatigue and wear. The live deck will in turn vibrate the sieves and their tensioning mechanisms, which weigh about two times the payload. Such a heavy steel structured live deck vibrates other system parts such as the hopper, supporting frame structure, sieve and supporting ribs. In addition, resulting vibrations are usually transmitted to the screen floor, plant offices, and screen attendants. The former issues reduce screening performance and increase maintenance cost, fatigue and negatively affect workers' health.

The total weight of a conventional screening system is about 22 times its payload (the amount of mineral being processed at any given moment). For example, for processing a mineral payload of 50 lbs, the conventional screening system will often weigh a total of about 1100 lbs. The conventional rotary-eccentric-shaft motors are designed to shake a weight that is significantly heavier than the mineral payload. This is the primary reason for the inefficiency of the conventional screening machines. The Smart Screens focus energy on the mineral processing payload and the weight of the vibrating screen elements (the "live" deck) is usually no more than 2 to 3 times the weight of the payload. This makes the Smart Screens more cost-effective and efficient.

Even though screening and size separations are not the single most energy intensive process in a mining or processing plant, they are often the major bottleneck in the overall process. Improvements in this area have demonstrated tremendous potential in both energy savings and production improvements.

A Smart Screen uses an advanced sensory system to continuously monitor the screening process and make appropriate adjustments to maintain screening efficiency. The massive electric rotary-motor-with-eccentric-shaft is replaced with either electromagnetic motors or miniaturized, ceramic-based motors in combination with multi-stage resonators. The "smart" motors are optimized so that the effectiveness and efficiency of the system will be increased by another order of magnitude.

Organization	Facilities/Equipment	Role in This Project
Albany Research Center (ARC)	Characterization laboratory and equipment, wear, erosion and corrosion facility.	Program management, materials specifications, sizing technologies
QRDC, Inc.	Smart materials, vibrations, energy management, screening, modeling, testing, analysis, and evaluation	Program management, smart materials, vibrations, energy management, screening, modeling, testing, analysis, and evaluation
Two Minnesota Mining Companies	Engineering departments, operating processing plants and the associated operations, milling, and maintenance systems. These two mining companies are keys to the project.	Engineering assistance, access to screening operations, staff access, field evaluation, steering committee
Minnesota Technology, Inc.	Business development and technology insertion	Business development and technology insertion
ProtoPhase, Inc.	Machine shop, metal bending, fabrication facility	Prototyping and low volume production
Smart Screen Systems, Inc.	Testing and production facility, engineering staff	Prototype design, function evaluation and validation, product assembly, large volume production, quality control, technical support, worldwide sales and marketing

Table 1 Facilities and Capabilities of the Partners

Motivation and Smart Screen Team

The iron and steel industry is extremely competitive, and recent world economic events have magnified the competition. The "smart" product development program aids the industry by introducing significantly more cost-effective and energy efficient technology to processing and production.

In this continuing product development work, the state-of-the-art smart materials, multi-stage resonators, and the recently patented Energy Flow Control (EFC™) and Vibration Control by Confinement (VCC™ technology are combined to create Smart Screens. This combination of technologies has been investigated and applied in critical systems in the U.S. Department of Defense. The U.S. Army, Navy, and Air Force have contributed to the development of this technology for use in military systems.

To successfully develop and commercialize Smart Screen Systems, a multi disciplinary project a team was put together. Table 1 shows the list of these organizations, their role, and capabilities. The participating mining companies in this project produce 31% (17.65 million tons) of U.S. iron-ore production. Currently, three four iron ore concentrators are using these high-frequency fine-screening systems and are also co-operating in the development of additional refinements and new screening process control schemes.

Smart Screen Approach

Smart Screen concept relies on two key technologies, namely smart materials and smart control. These two key areas plus the overall approach are described in this section.

The current generation of Smart Screens use electromagnetic motors to drive the screening system. Looking to the future, Smart Screen Systems, Inc., has found that piezoelectric ceramic materials (such as PMN=Lead Magnesium Niobate, and PZT=lead zirconate titanate) are particularly well suited for applying dynamic forces, and can deliver the required shaking function to sieves. In addition, these PZT materials will function as collocated sensors and actuators for active control of the shaking action and process automation. Piezoelectric actuators can simultaneously sense vibrations in the structure while applying a force to the structure. This approach relies on a closed loop control system that separates the applied control voltage from the voltage induced in the piezoelectric material by vibration in the structure.

Piezoelectric sensors and actuators for this program may be in the form of patches, monolithic shapes, or multi-layer stacks. Monolithic shapes are fabricated in a wide range of geometries. The equation for the blocking force shows that the highest forces are obtained when the area of the actuator is large and the thickness is small. In fact, the patch actuator is a particular form of the monolithic shape with a high aspect ratio that can provide high forces in the direction of poling and generate relatively large voltages when a force is applied along the length. A multi-layer stack is comprised of a stack of thin layers of material connected electrically in parallel. These stacks multiply the force or extension by the number of layers providing higher forces or strains than a monolithic shape of similar dimensions. The multi-layer stack may be used to reduce the voltage required to obtain the desired level of actuation or shaking.

The collocated sensor/actuator sets may be also be based on PMN stacks that are readily available in the commercial market. The PMN sensor/actuators have been developed for high performance military applications. They can be fabricated in a variety of sizes. For example, 2" diameter and 4.5" long rod-shaped stacks have been successfully fabricated and tested. These stacks have the capability of providing 16000 lbs blocked force and 4.5 mils free displacement. The actual blocking force is determined by the material, size, and voltage. The PMN-based collocated sensor/actuator sets are utilized in conjunction with the state-of-the-art signal processing and control algorithms. Switched Capacitive Amplifies (SCAMP) may be employed for driving capacitive loads. They can be operated with a time delay less than 10 micro-seconds with voltages in the range of 150 V to 1000 V.

In the future, smart and effective PZT and PMN actuators may be used as the main engine (or motor) to generate the required shaking. A multi-stage resonator may be used to amplify the displacements and accelerations so that the screening function is optimized. For example, stacked cantilever beams may be used as the preliminary design of the multi-stage resonators. Combination of the multi-stage resonators and smart materials offers full control and precision of the shaking function.

In addition to their small size and high blocking force, they can operate at frequencies ranging from DC to Mega Hertz. This feature will offer a precise tuning the screens for the best throughput and effectiveness. On the top of the steady-state vibrations (i.e. shaking), we superimpose a high-energy impulse in order to prevent blinding in sieves.

Driving the motion of the current generation of Smart Screens are two electromagnetic motors (as shown in Figure 1). Typically, because of their design, conventional vibratory screens are limited in their direction, speed and range of motion. These restrictions allow conventional screens to become quickly blocked or "blinded". It is not unusual to have as much as 50% blinding on conventional screens within 24 hours of operation. The energy flow control technology in Smart Screens has the ability to regulate the screen vibration parameters via a standalone PLC. This feature increases the operator's ability to minimize blinding and maintain optimum screening efficiency.

In terms of smart control, Smart Screens rely on the patented Energy Flow Control technology. It is the combination of smart materials and this vibration energy managing method that makes the approach unique and innovative. Energy management may include energy diversion, confinement, dissipation, conversion, and cancellation. The underlying vibration energy management concepts are not new and have been developed for and used in a number of military applications. The basic energy management concept has been practiced in other fields. Examples are heat management in electronic circuits, flow management in thermodynamic systems, money management, and electrical and thermal energy management in buildings and mechanical systems. However, with the exception of the work by Dr. Allaei and Smart Screen Systems, Inc., the vibration energy management concepts have not been previously applied in the context described here.

Energy management is used to deliver focused dynamic (or vibration) energy to the screens through which the physical separation of the material takes place. It has been demonstrated that optimizing energy delivery can increase the process output by a factor of six (6). For example, if a plate is used as a resonator, while input is maintained at the same level, its output can be increased by a factor of six when its elastic energy is focused over 67% of its surface.

The theoretical advantage in the development of the Smart Screen technology is found in the ability to control the flow of energy and in confining this energy to the working screen surface itself — rather than having energy siphoned off to shake the entire screen machine and the surrounding structures. The Smart Screen designs eliminate or downsize many of the structural components typically required for the operation of conventional screens. As a result, it is possible to provide more working screen surface within a given plant space "footprint".

Prototype Description

Reducing the current energy usage, decreasing maintenance cost, and improving throughput in fine screening operations are not trivial tasks. Care has been taken to ensure that economic and engineering data generated in the laboratory, pilot, and plant-scale research and testing are truly scalable to the industry needs. Technical barriers that have been overcome during the development phase are listed below:

- Miniaturization of motors that will generate sufficient force and displacement.
- Anticipating potential material fatigue expected in systems that operate at resonant frequency.
- Effective packaging for survival in a corrosive process environment.
- Development of effective techniques for reducing or eliminating screen blinding and plugging.

Figure 1 shows the first single-screen Smart Screen. It is apparent by the simple design concept that we are utilizing a single panel screen which is driven by two electromagnetic motors. The screen is mounted in the unit so that the deflection of the screen is impeded from transferring to the rigid frame and base – and, ultimately, to the structural steel plant platform. The rigid screen support structure is also isolated from the structural surroundings. The unit is fabricated with stainless steel, to control the effects of corrosion on the useful life of the equipment. The design of the single-screen unit is purposely fabricated so that it can be installed in a typical plant process environment where spills, high humidity and extremes in temperatures can exist.

Figure 3 shows the production Model S3i-102 that recently received the coveted *R&D Magazine* "R&D 100" award — as one of the technologically most significant innovations of 2003.

Results and analysis

Controlling the flow of energy so that the vibration is isolated to the screen itself significantly reduces the power required to accomplish this work. The primary benefits are found in an increase in cost-effective throughput and productivity.

A number of secondary economic benefits are found in energy savings (i.e., shaking only 150 lbs instead of 1100 lbs per machine). For example, a large concentrator might have more than 100 high-frequency fine screens and more than 40 lower-frequency screen in

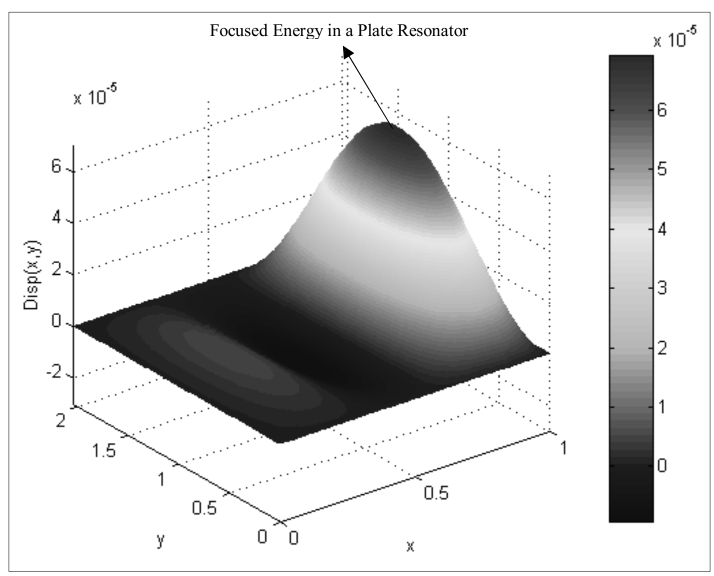

Figure 2: A plate resonator with focuses energy over a limited region

machines. At such a plant, the Smart Screen technology will shake only 20,920 lbs., instead of 118,550 lbs. — an 82% reduction in vibrating weight. Electrical energy makes up a large part of plant operating budget. Excessive screen weight and the inefficient energy management of conventional screens tends to increase operating costs and limit the overall process line efficiency.

The third economic benefit, significant for plants that need to manage Silica content in the pellet fines, is in the Smart Screen's ability to control the desired cut and limit the passing of "middling" particles that can carry Silica into the flotation process. Operation of a more efficient screen improves Silica management and increases process line productivity. Either of these outputs will be greatly beneficial to iron-ore processing.

Specification	Conventional Screening Machines	Smart Screen Systems	Advantages
Noise	90 - 120 dBA	Usually lower than plant background noise	Worker health
Maintenance	High	Very low	Significant reduction in maintenance costs
Weight	1,080 lbs	200 to 230 lbs	79% reduction
Power Consumption	1,975 W	1,481 W	75% reduction

Table 3 Comparison between conventional screening machines and Smart Screen Systems

The Smart Screens have demonstrated their ability to deliver this very substantial economic benefit — particularly in plants employing flotation.

Smart Screen technology requires far less maintenance to keep on line when compared to conventional screens. There are no bearings to lubricate, no wear plates to change, no springs, nuts or bolts to inspect, repair or adjust. Additionally, the Smart Screen panels require no tensioning either when installed or as part of their periodic maintenance. All Smart Screen panels are supplied as self-contained pre-tensioned units. This feature greatly simplifies installation and maintenance which can now be performed quickly, safely and efficiently.

Conventional vibratory screening machines are noisy machines. The design theories and technologies used in Smart Screens virtually eliminate problems associated with excessive vibration or noise. This greatly enhances the workplace environment and helps to maintain health guidelines related to noise.

Other benefits are in the area of environment and health. Smart Screen Systems certainly have a much lower environmental impact due to reduced energy usage and less throw-away parts such as bearing, lubrication, bolts, etc. Anticipated improvements to worker health and safety are important improvements. Smart Screen Systems reduce noise and vibrations and thus, eliminate worker exposure to excess noise and vibrations. Furthermore, safety is improved by reducing noise. The latter offers a better worker environment to communicate and being fully alert at their tasks. It is well know that excess noise can cause distraction and lack of focus among workers.

The key functional features of the Smart Screen Systems are compared with conventional screening machines as shown in Table 3. These features are based on the measurements made on the first prototype. Data to be collected during field tests and evaluations will be used to complete this comparison chart.

Figure 3: Model S3i-102 Smart Screen

Summary and Future Directions

We have taken the basic concept of a vibrating screen and deployed Smart Screen technologies to better fit the production, energy conservation and worker health and safety needs of our customers. We identified the need for a design change, applied a proven technology - namely smart actuators and Energy Flow Control™ (EFC™) and Vibration Control by Confinement (VCC™ and assembled a strong team to carry out the tasks. Today we have entered the market and demonstrated some impressive screening results. Wider installation of these Smart Screens will ultimately help processing plants become more productive with less maintenance — while eliminating the excess noise & vibration problems that have come into focus as major worker health concerns.

Development is already progressing on the second generation of Smart Screens which will further enhance the already significant benefits of this new technology. Smart Screen Systems, Inc. is developing "self-teaching" Smart Screens which adapt to the operating conditions in which they are running. Soon, Smart Screen Systems, Inc., expects to combine the two motor technologies (electromagnetic and PZT) to create a hybrid screening machine that will offer significant new operating advantages and support process control schemes previously unavailable to vibrating screen operators.