SUSTAINABLE MANAGEMENT STRATEGIES IN MINING INDUSTRIES: INTRODUCTION OF RECONFIGURABLE AND ADAPTABLE TECHNOLOGIES

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ABSTRACT

There is a great pressure for mining industries to implement innovative mining machineries designs that will keep them competitive. Making large cuts and managing long term costs requires an introduction of reconfigurable adaptable technologies (RAT). Mining machineries are very vital in the mining industries for the beneficiation and exploitation of mineral particles into different sizes. Breakdown due to unforeseen contingencies has reduced the productivity of these machines thereby reducing the competitiveness, availability and reliability of these machines for the set production target made by the company. Also since human wants are insatiable according to economists, fluctuation in the mineral concentrates demands has been an inevitable scenario thus, reducing the efficiency of the mineral beneficiation industries. During the mineral concentrates demand peak, most of these industries do not have option than to purchase another beneficiation machine in order to meet up with this high demand. A thoroughly investigated solution called RAT mining machines that can cover the loop holes created by machine breakdown, ensure feasibility of company set monthly production target and can meet the quantity and quality of mineral concentrates needed by customers is proposed as a potential solution to address this turbulent conditions that the mining industries are facing. This paper presents possible future directions of reconfigurable mining and beneficiation machine concepts as applicable in mining industry. Different ways in which these potential reconfigurable mining and beneficiation can assist with exploitation and beneficiation of mineral particles were also discussed in this paper. Also, the opportunities, strength, weakness and threats in the mining equipment business were also discussed in order to evaluate the efficiency of producing RAT. In order to boost the development and application of these RAT, adequate capital (funds) should be made available for research and development in these industries and adequate skills and training should be provided to boost the technological competence of engineers designing, utilizing and managing the RAT.

Key words: Reconfigurability, adaptability, vibrating screen and mining machines.

INTRODUCTION

As the mining industry emerges from global financial crisis (global recession), many mining companies are already outlining plans for moderate to aggressive growth over the short to medium

term. Thus, new enablers are needed in both product development and manufacturing systems (Al-Zaher *et al.* 2013). Currently there is a rapid growth in literature addressing the enablers that will guarantee sustenance and competitiveness of business especially in the mining sector. While production volumes increase with expectation, there is a need to reduce operating cost of the mining companies through the introduction of innovative mining machineries that can cater for changes. The influence of machines in mining industries goes far beyond its daily usage, but effective measures that will ensure its availability, reliability, maintainability and responsiveness to varying market condition is also important to ensure effective management of its lifecycle, which in the long run will ensure high productivity of mineral concentrates demanded by the customer at a particular time't'. In today's mining environment, there is a need to design and develop intelligent RAT machines using reconfigurable manufacturing principles introduced by Koren *et al.* (1999), which are cost effective and will ensure the production of varying mineral concentrates demanded by customers, thereby ensuring cost-effective operations in the mining industries. Reconfigurability also known as changeability is very essential for improving the functionality and internal operation of any mining machine used in industries. In order to develop RAT, a study of current machinery is essential in determining the area that needs to be reconfigured. This paper introduces new ways that can be adopted to develop reconfigurable mining machineries that will ensure cost-effective operations in the mining industries. The next subsequent sections of this paper, presents the review different works done in manufacturing, automotive and other related service industries. The paper further went on to present some of the proposed reconfigurable technologies for sustenance of mining industry. The paper concludes with a SWOT analysis that distinguishes between applications of current methods over the proposed reconfigurable principles.

RELATED WORKS

Researchers have often associated mineral concentrates demand as being uncertain (Ben-Ner et al. 2012) as well as machine break down as inevitable scenario (Bosnjak and Zrnic, 2012 and Gharahasanlou et al., 2014), thereby hindering most of mining companies from meeting their customers' target. In view of this, some researchers sees it as the opportunity to develop sustainable measures which will ensure the production of these varying mineral concentrates needed by the customers in order to cover up for the loop holes caused by the mining machines breakdown. This remarks prompts policy makers to think about effective management framework for sustenance of the mining operations through introduction of innovative technologies. Case studies of five different companies in South Africa carried out by Makinde (2014) showcased that machine break down and customer's varying mineral concentrates has been a major threat reducing the productivity of mining industries. To combat this plight, the application of reconfigurable manufacturing principles and characteristics such as modularity, customization, diagnosability, integrability e.t.c as described by Mehrabi et al., (2002) has been envisaged to ensure the exploitation and beneficiation of varying mineral concentrates demanded by the customers in the mining industry (Makinde et al., 2013). Ramatsetse et al., 2013 reported that the introduction of reconfigurability principles in the production of mining and beneficiation machines will allow the production of scalable and portable mining machines for underground mining systems with limited space capacity as well as giving the owners of small to medium scale mining enterprises the opportunity to afford these machines at a reduced cost for their mining operations. Also, there has been some effort initiated to introduce automated mining systems that will enhance operations in mining industries. The application of

reconfigurable and adaptable technologies is a line that is raising many interests in advanced manufacturing. The following section presents the applications of RMS principles in various sectors such as Manufacturing, Automotive, and Service industries to boost their business operations, which thus validates and give an evidence of the usefulness of reconfigurable manufacturing principles in achieving the production of varying mineral concentrates demanded by the customers.

Application of RMS in manufacturing industries

RMS has been widely applied in manufacturing industry in order to provide the customized flexibility needed at a particular period when needed. (Koren and Shpitalni 2010) described RMS as the responsiveness commotion that is designed to add production capacity as the market grows and also to add functionality as the product changes. (Aquilar *et al.* 2013) documented a study that demonstrates the design, refinement and implementation of reconfigurable machine tool with the aim of providing a flexible platform for both turning and milling operations. Meanwhile (Gwangwava et al 2013) designed a reconfigurable bending press machine that will aid manufacturing companies' achieve geometric transformation and productivity adjustment of sheet metal operations using modularity, integrability, convertibility and customization principles.

Application of RMS in automotive industries

Automotive industries are pressurized by the high demand of vehicles, motorbikes, and other related transportation modes to deliver variety of products for both local and international consumption. The utilization of RMS in this instances will assist achieve "***just in time***" in automotive industries. Arch-type RMT designed and developed in university of Michigan by Yoram Koren, is one of the innovative technologies intended to assist automotive industries machine engine blocks which often consists of complex geometries and variety of angles. (Al-Zaher et al. 2013) proposed a framework that aids automotive manufacturing industries to design their reconfigurable assembly framing system such that it could provide a suitable platform to support vehicle structures at different stages of assembly depending on the structure of product required by the customers. Kong and Ceglarek (2003) proposed an integrated approach of integrated approach and framework for developing a reconfigurable assembly fixture that could be used in the production of varieties of products required by the customers in manufacturing industries using modularity, scalability, convertibility and customization RMS principles. Nyaka et al., 2013 proposed a reconfigurable supply chain management system that could be used to effectively manage the production of varieties of press brakes that could be in Press Tool Industries. Recently, (Simon et al. 2014) introduced a reconfigurable tooling system for producing plastic shields at low investment costs using modularity, convertibility and customization principles.

RMS PRINCIPLES AND ITS DEFINITIONS

Reconfigurability is defined or viewed as the ability to convert a system quickly to the production of new models, able to adjust capacity quickly, and able to integrate technology and to produce an increased variety of products in unpredictable quantities. It is also known as customized flexibility. In view of this, a reconfigurable product can only be produced using reconfigurable manufacturing systems (Koren et al., 1999). The characteristic of reconfigurable manufacturing systems as described by Mehrabi et al., 2002 is highlighted in table 1 below:

Table 1: RMS characteristics as applied in product development

Rms Charateristics	Description
Convertibility	Is the ability to easily transform the functionality of existing systems and machines to suit new production requirements.
Scalability	Is the ability to easily modify production capacity by adding or subtracting manufacturing resources (e.g. machines) and/or changing components of the system.
Modularity	Is the compartmentalization of operational functions into units that can be manipulated between alternate production schemes for optimal arrangement
Integrability	Is the ability to integrate modules rapidly and precisely by a set of mechanical, informational, and control interfaces that facilitate integration and communication.
Customization	Is the ability to produce a particular product based on the customers' requirements, designs, specifications and configuration in order to ensure customers satisfaction.
Diagnosability	Is the ability to automatically read the current state of a system to detect and diagnose the root causes of output product defects, and quickly correct operational defects.

RECONFIGURABLE ADAPTABLE TECHNOLOGIES FOR MINING BUSINESS OPTIMIZATION

Reconfigurable drill rig

The reconfigurable manufacturing rig is also known as a multi-function drilling rig. The need for multifunction drilling rig is highly necessary in mines in order to save time used very drilling a large number of holes on a vast rock deposit. The reconfigurable drilling rig is made up of an internal combustion engine, masts or derricks, the air compressor, three drilling pipes or rods, shank adaptors, arms, hydraulic cylinder and the drilling bits and three drilling tables. The internal combustion engine is used to transmit power from the shank adaptor to the drilling pipes and down to the drilling bit for the drilling operation. In this system, the central internal combustion engine powers the three drilling rods coupled to the three drilling bits for drilling operations. The spacing between the three holes to be drilled is achieved by the expansion and the contraction of the hydraulic cylinders. The three drilling bits is being cooled during drilling operation by compressed air supply to each drilling bit through pipes. The mast or derrick supports the drilling rods or pipe, the internal combustion engine and the drilling bits. The drilling table provides the seat for drilling pipe attachment for further drilling operation.

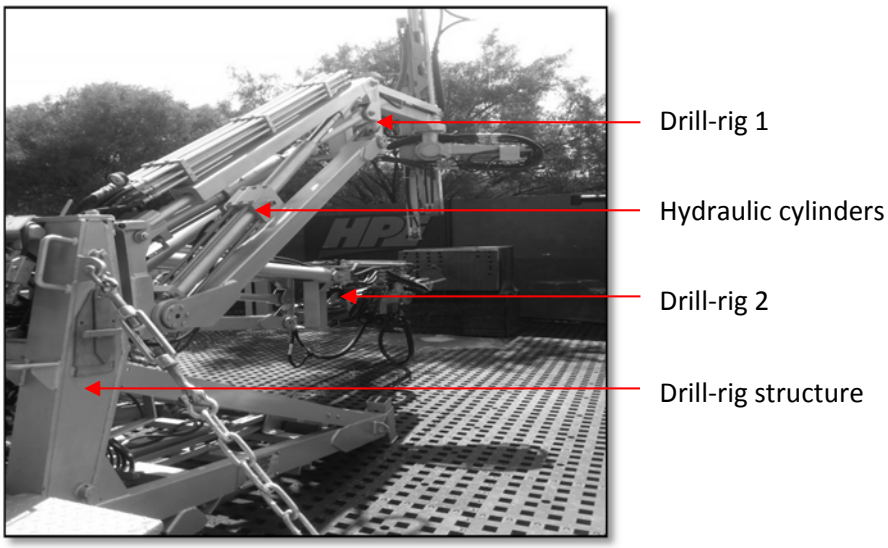

Figure 1: Multi-drill rig

The reconfigurable drilling rig intends to adopt the RMS principles by integrating to the RDR at its standard state, one or two derrick modules as well as cylinder system that will ensure the extension of the derrick systems on which the drilling bits will be fixed to achieving simultaneous drilling action of the integrated drill bits and the centralized bit on a mine ore deposit. This reconfigurable technology will also be useful in achieving simultaneous drilling of boreholes on rock surface at varying spacing through the action of the hydraulic cylinders. Also, the drilling of different sizes of holes depending on the level of rock fragmentation required on an ore deposit is also achieved using drill bits modules required for a particular mining purpose(whether soft or hard rock mining).

Reconfigurable gravity and magnetic separator

The reconfigurable gravity and magnetic separator uses two principles to separates mineral particles into four fractions namely, less dense magnetic minerals, less dense non-magnetic minerals, dense magnetic mineral particles and dense non-magnetic mineral particles. These two principles are the gravity and magnetic separation techniques. Gravity separation technique is an industrial method of separating two components, either a suspension, or dry granular mixture where separating the components with gravity is sufficiently practical: i.e. the components of the mixture have different specific weight. All of the gravitational methods are common in the sense that they all use gravity as the dominant force. The most notable advantages of the gravitational methods are their cost effectiveness and in some cases excellent reduction. Magnetic separation technique is also a method in which magnetically susceptible material is extracted from a mixture using a magnetic force. This separation technique can be useful in mining magnetic metallic minerals as it is attracted to a magnet. The reconfigurable gravity and magnetic separator is made up of the following parts namely;

i. **Hopper**: this is the chamber that is used for feeding the unprocessed mineral particles.

ii. **Overflow Chamber**: this chamber is made up of the overflow outlet and the overflow strings of rods hooked to the magnetic balls. The overflow outlet is the outlet for collecting less dense non-magnetic mineral particles.

iii. **Underflow Chamber**: this chamber is made up of the underflow outlet and underflow string of rods hooked to the magnetic balls and spaced at regular intervals. The underflow outlet is used for collecting dense non-magnetic mineral particles.

iv. **Electric Stirrer**: this equipment is used to stir the slurry (suspension of unprocessed mineral particles) continuously until optimum beneficiation is achieved.

The suspension of unprocessed mineral particles (mineral slurry) is fed through the hopper into the separation chamber and stirred continuously for 15 minutes. During the stirring process, the less dense non-magnetic mineral particles are collected at the overflow outlet, the less dense magnetic mineral particles are attracted by the magnetic balls in the overflow chamber, and the dense non-magnetic mineral particles are collected at the underflow outlet while the dense magnetic mineral particles are attracted by the magnetic balls in the underflow chamber. The less dense (light) and the dense magnetic mineral particles (heavy) are then demagnetized using a demagnetizer.

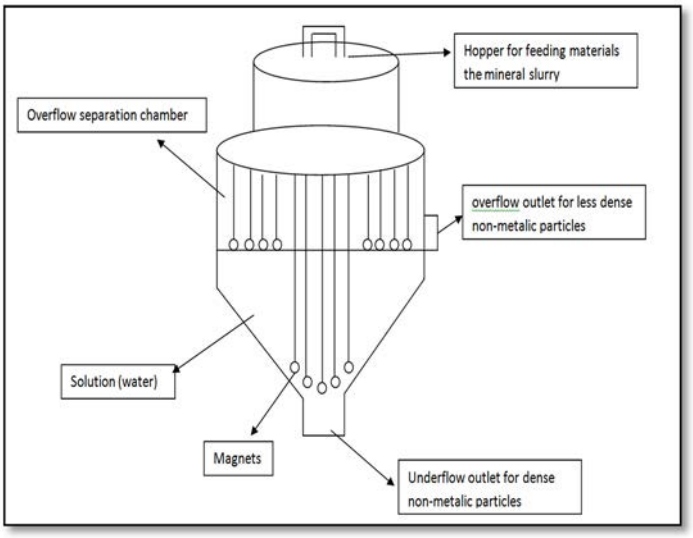

Figure 3: Reconfigurable magnetic separator

In other words, this mining machine is made up of magnetic ball modules, electric stirring module and the solution (water) module; in which if there is a need to separate slurry mineral particles that does not contain metallic particles in this machine, then the magnetic ball modules are detached from their housing unit since it is not required for this slurry mineral particles separation but if a slurry mineral particles containing metallic particles are to be separated with this machine, then the magnetic ball modules needed for the metallic mineral particle separation of this slurry particle is connected back to it housing unit in the machine. Reconfigurability principles proposed in this beneficiation machine involve integration and de-integration of magnetic ball modules in order to make a mining beneficiation machine to be able to perform effective separation of mineral particles using gravity separation only if the mineral particles or slurry to be separated are non-magnetic mineral particles as well as performing gravity and magnetic separation if the mineral particles to be separated is magnetic mineral particles or slurry.

Reconfigurable conveyor system

Although traditional fixed conveyor systems have been one of the leading factors in lean management over the last two decades, they have lost their luster—not just to those who control the purse strings, but also for engineers who have long dealt with the headaches of inflexible systems, long lead times, and production shutdowns while the systems are installed. As conveyors have become a necessity on the mining plant floor, conveyor manufacturers have attempted to respond to end-users' needs for flexibility by creating truly modular, reconfigurable systems that will ensure optimum feeding of mineral concentrates to different modular beneficiation plants as shown in Figure 4.

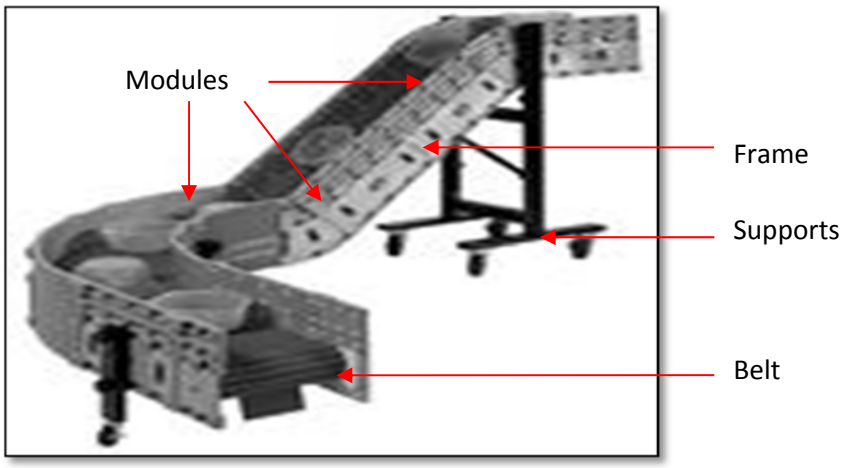

Figure 4: Reconfigurable conveyer system

Reconfigurability proposed in this equipment involves the integration and de-integration of modular conveyors frames at varying angles to ensure the transfer of mineral particles to be processed to various processing stations or stock pile using a well defined/mapped path or optimal path plan within the mine, thus avoiding obstacles, saving time as well as cost of running the mining operations in the mining industries.

Reconfigurable Vibrating Screen (RVS)

RVS is newly improved screening equipment aimed at increasing productivity at the same time achieve a high processing efficiency (Ramatsetse *et al.,* 2013). The RVS design relates to a new improved vibrating screen for use in screening materials such as bulk granular and particulate materials. The RVS uses a simple theory of reconfigurability to increase its capacity therefore at the same time enhancing the productivity of the machine. The RVS consist of two torsion bars also known as structural beam at both ends which provides stability of the screen structure, minimize torsion and prevents failure of side plates as well as a reconfigurable screen frame structure to achieve varying configurations needed for separating varying mineral concentrates demanded by the customers. (Li *et al.,* 2013) emphasized that the beam or torsion bar is the main member to keep the side panel of the screen stable. At its maximum configuration the screen exceeds the capabilities of a similar conventional screen with the same specifications. The RVS also known as the multi-functional processing machine addresses the three most important principles of Reconfigurable Manufacturing Systems (RMS) such as scalability, modularity and integrability.

Reconfigurability proposed in this equipment involves the integration and de-integration of screen mesh modules in order to increase the capacity on one hand and on the other hand improve the efficiency of mineral beneficiation that can be carried out on the machine. Also, production of varieties of mineral concentrates of different sizes is also feasible on the machines through the use of appropriate screen mesh of adequate size that could be found on the module library of the proposed reconfigurable beneficiation machine. Finally, Makinde et al. (2015) developed holistic methodologies for optimal RVS machine design and development, which thus provides the designer of this novel machine with necessary design parameters needed for mechanically designing and developing the machine as well as the control models (i.e. functional requirements) required to ensure the optimal functioning of this machine at different configurations.

Reconfigurable Condition Monitoring (RCM) machines

As already discussed, a reconfigurable condition monitoring machine is a machine that ensures effective maintenance process both in surface and underground mines. A proposed example of such machine is shown in Figure 5 below.

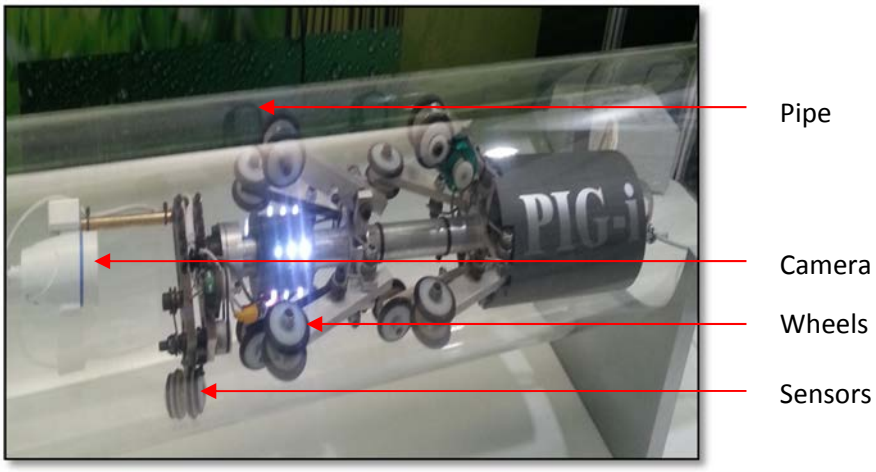

Figure 5: Reconfigurable condition monitoring (RCM) machine

It uses both sensor and cameras to locate a possible area that has defaults especially in piping systems.

The implementation of RCM machine will results in the following questions being asked:

i. What types of machines do we need to monitor in the mining industries?

ii. What are the failures experienced by these machines?

iii. Information on maintenance and risk assessment analysis carried out in the company in order to produce quality vibrating screen products.

iv. What are the causes of failure, the duration of failure and how are these failures averted in order to ensure mining and processing operation continuity?

v. What are the different kinds of tests done to assess the present performance of these mining machines?

These machines are made reconfigurable by fixing the modules that can be used to perform any of the aforementioned tasks in the RCM machine. RCM machine incorporates an RMS principle that aids it to perform condition monitoring in hasty mining environments through effective monitoring of the inside surface of converging and diverging piping units of water pumps with various diameters using designed customized flexible spider-liked wheels embedded with camera to ensure the prediction of cracks and wear inside the pipes before failure or damage occurs. The extension and contraction (which thus ensure some degree of gyration or freedoms) of the designed flexible spider wheels of the RCM machines ensures its ease of penetration into the piping unit to be monitored.

BENEFITS OF USING RAT IN MINING INDUSTRIES

As already discussed, RAT will be advantageous to ensure rapid response to requirements and challenges of mining industries as well as turbulent mineral market condition, thereby achieving the goal to gaining a competitive edge over the competitors. It is envisaged that reconfigurable mining machines will enhance the productivity and safety in mining operations and also risk exposed on human beings. In view of this, a comprehensive envisage SWOT analysis for introducing these proposed RAT machines was envisaged as depicted in table 2, which in the long run will ensure the production of varying mineral concentrates required by the customers in a cost-effective way.

Table 2: SWOT analysis of using traditional mining machines as opposed to the proposed RAT.

Perspective	Traditional Mining Machines	Reconfigurable Mining Machine
Strength	Restricted and perform within feasible and hospitable, environment, productivity restricted to the dedicated bucket size of the machine.	Reach areas where normal human being cannot get to, high mineral concentrates productivity, reduced mining and maintenance operation cost.
Weakness	Are completely dedicated.	Manual reconfiguration proposed which increase the production lead time.
Opportunities	Create employment.	Adapt to varying and changing environmental and demand conditions.
Threats	This technology will soon be outdated due to the introduction of reconfigurable mining machine with high sustainability.	Design, development, assembly and disassembly process of these machines are complicated.

However, the threats and the weakness can be overcome through the provision of adequate funds (by the government) for training and research development of different engineering institutes in South African university institutions; on how to build in intelligent RAT machines that are cost-effective for optimal mining operations in the mining industries.

CONCLUSION

Reconfigurability principles have been pictured as useful tool or technique for ensuring the responsiveness of mining systems and operations in the mining industries. Success, usefulness and the impact of RMS application in different manufacturing and automotive industries in achieving cost-effective operations in these industries create a clear illumination of the relevance of the RMS principles in meeting changing and turbulent mineral market conditions in the mining industries. The different architectural design characteristics such as modularity, scalability, integrability, convertibility and diagnosability etc. has been envisaged to contribute immensely to the success of the design and development of reconfigurable mining machines such as reconfigurable drilling rig, reconfigurable gravity and magnetic separator, reconfigurable conveyor systems, reconfigurable vibrating screens, reconfigurable condition monitoring systems and other related equipments, which will enhance the production of varying mineral productivity, enhance optimal maintenance operations on some mining machines, eliminate risks and mining accident and create job opportunities for vulnerable citizen in South Africa and the global world at large. In order to boost the development and application of these RAT, adequate funds should be made available for research and development in these industries and adequate skills and training should be provided to boost the technological competence of engineers designing, utilizing and managing the RAT.

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