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Analysis and performance investigation of a reconfigurable vibrating screen machine for mining and mineral processing industries

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Abstract

Reconfigurable Vibrating Screen (RVS) machine is an innovative beneficiation solution designed for screening mineral particle into various sizes and volumes demanded by the customers at any particular time in a cost-effective manner. In order to ensure optimal functionality, reliability and maintain ability of the RVS machine when used in the mining industry. There is a need to investigate the performace of this machine using smart measurement and monitoring technology in order to effective using data acquisition system; DAQ which recover raw perfromance data via the sensor connencted to be machine. Multi-point modelling experiments were conducted in order to measure stress distributions on various sub-components of the RVS machine at different configurations of 305 mm × 610 mm, 305 mm × 1220 mm and 610 mm × 1220 mm respectively. Furthermore, sets of experiments were conducted to determine the stress distribution experienced on the RVS machine structure using the worst loading conditions. The results of the experimental study revealed that the current stresses on the RVS machine subsystems during the granite run-off particles screening operation are subjected to pressure of 5.01 MPa, 1.25 MPa, 0.55 MPa, 0.37 MPa and 1.76 MPa, which are less than the critical or maximum threshold stress limits of these RVS machine subsystems of 20.8 MPa, 7.4 MPa, 4.3 MPa, 16.3 MPa and 13.6 MPa respectively as determined through simulation.

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Keywords: Vibrating screen; mining industry; mineral processing

1. Introduction

Frequent mining machine breakdowns are limiting the competitiveness of mining industries globally, which leads to fluctuating mineral market conditions [1], high cost of purchasing and maintaining machines [2-4]. Some critical problems will be a direct negative influence on the mineral processing plant if the reliability of a vibrating screen cannot meet the production requirements. Preliminary mechanical design, medium-term manufacture, and equipment utilization are some of the critical activity that have been identified in pilot testing in order to improve the design and reliability of vibrating screens used in the mining industries. Most of the existing conventional screening machines are designed for steady and predictable production by various mining organisations. But due to increase in demand for mineral particle products, mining organisation are under pressure to seek for alternative beneficiation machine solution that will address these challenges.

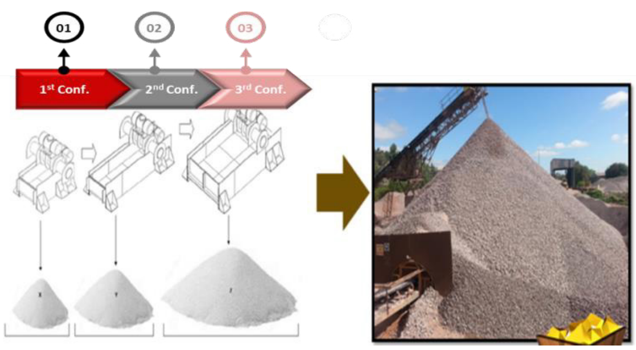

Fig. 1. Productivity pattern for mineral processing industry.

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Authors Baragetti [5], proposed new structural solution for vibrating screens, while other authors such as Csizmadia et al. [6], Csizmadia *et al.* [6], Jiang *et al.* [7], Li *et al.* [8], Li *et al.* [9], Nianqin et al. [10], Wang *et al.* [11], Wolny *et al.* [12], Yan *et al.* [13] determined optimal parameters for vibrating screens. This study introduces the newly developed mineral processing machinery called reconfigurable vibrating screen (RVS) that can be utilised to sieve various mineral particles to required specification as well as to deal with the fluctuation demands. Fig. 1 depicts a typical productivity pattern that could be experienced in a particular time frame in the mining industry. Thus, this paper introduces the design and structural optimization of the newly developed mining and mineral processing machine called the reconfigurable vibrating screen (RVS) that can be utilized to sieve various mineral particles to required sizes. This novel machine design was achieved by adopting ideas of reconfigurable manufacturing system (RMS) technologies originating from Koren [14]. The characteristics that was adopted in the design of this machine as indicated by the research works of Mehrabi and Koren [14] are convertibility, scalability, modularity, integrability and customization. Conventional screening machines with a dedicated screen structure produces a specific mineral concentrates which is equal carter for demand to account for the low peak seasons, resulting in in companies not meeting their monthly and yearly production targets, thereby reducing the their competitiveness. However, the proposed design called RVS machine equipped with an adjustable structure allows more production and provides larger capacity intakes as compared to its counter parts. Ramatsetse and Makinde [2], [3] and [4] explained the important characteristics of the RVS machine; the most screening ensures that the machine can perform a wide range of functions such as dry and wet screening. The next section of this article presents literature carried out on the various works on screening performance and new emerging screening technologies.

2. Related works on performance evaluation of vibrating screens

Vibrating screens are understood by various mineral processing experts to be an effective solution to address separation of mineral particles into various sizes as demanded by the customer in mining and mineral processing industries [15-19], but a wide gap remains between conventional screening machineries and their capability to respond to fluctuating market conditions [21-23]. Despite this, current conventional screening technologies such as inclined, grizzly, horizontal, resonance, dewatering, oscillating, banana, modular, revolving and high frequency have already achieved commercial success in the steady and predictive market conditions around the globe. In addition to this, production losses owing to downtime experienced during the maintenance of conventional screening machine have also contributed to the inefficiency of this machine. In addressing these problems, a radical shift to introduce new technological solutions that will be able to deal with ever change market condition is required in the mining and mineral processing industries. To date, various authors have proposed various strategies and ideas that showed how production lost due to machine downtime and failure can be recovered. Makinde *et al.* [3] showed how production can be recovered from a production halt due to maintenance by utilising a RVS machine in a mining industry. Park and Matunhire [24] investigated factors that influence the determination of discount rate in the economic exclamation of mineral development projects. Based on the analysis of literature, it can be noted that most developments in screening machines are intended to enhance the operation and performance of the machine. Some of the developments include combining two screening units of different drive systems to improve the efficiency and processing capacity [10]. Other interesting research in this field; investigates the increase of the degree of freedom of the vibrating screens, dynamic analysis, parametric resonance, static & modal analysis [25][26][27][28][29]. To date some of these aforementioned authors have proposed novel solutions to solve problems of particle size, moisture, intensity of screens, feed rate, screen size, which, as mentioned, are some of the factors affecting the performance of the screen. Research and development in the area of screening machines is gradually gaining popularity in addressing problems faced by mineral processing industries. The current conventional screening methods are largely based on the demand at the time of processing, but due to uncertainty associated with the demands, these screening solutions are unable to address the issue of varying demand levels. Hence, to optimally design, prototype and commecialise the RVS machine that has the potential of meeting fluctuating mineral concentrate demands.

3. Materials and methods

The step by step process of how the study was carried out in order to determine the performance of the RVS machine.

Step 1*: Selection of the material used for screening the RVS machine*
Step 2*: Dynamic modelling and simulation of a RVS machine model using ANSYS software to establish the critical stresses at which the RVS machine subsystems will fails when operating at the highest mineral loading conditions.*
Step 3*: Fitting and connection sensors to the machine and the DAQ for the machine performance condition monitoring.*
Step 4*: Analyse the results obtained from the dynamic modelling and experimental results.*

3.1 Selection various mineral samples and description of the RVS machine

The first step carried out in the RVS machine involves the selection of various mineral products such as granite (crushed), coal, iron ore, gold ore, chrome ore and limestone. The samples were collected from various mines and quarries. The properties of these minerals are depicted in Table 1. Various screen mesh sizes used on the RVS machine were collected from one of the leading suppliers known as Multo-tec. The authors specified a set of design criteria that suit the problems that the RVS is addressing. Fig. 2 shows a proposed materials and methods used for the RVS machine performance evaluation.

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Fig. 2. Various mineral particle samples used for the RVS machine performance evaluation

Table 1. Properties of aggregate samples

Aggregate samples	Bulk density (kg/m^3)	Undersize (%)
Granite (crushed)	1554	30
Coal	960	30
Iron ore	2595	30
Lime stone (ground)	945	30

The scale measurements taken prior to screening indicated that the maximum mineral particle layer thickness for effective sieving was approximately 30 mm. The design of the vibration screen structure required that the mass of the mineral sample used for experiments must be known. The bulk density of the mineral samples was determined which in turn was used in conjunction with this layer thickness and vibration screen dimensions to compute the theoretical mass of the mineral samples on the vibration screen. To determine the bulk density, a calibrated scale was used to measure the mass of mineral samples. The experimental set-up of this research is presented in Fig. 5.

3.1.1 RVS machine description

The RVS is made up of major systems and subsystems, which can be further classified into mechanical and control systems. The components includes, frame, suspension, side plates, screen panels, torsion bar, vibrating motor. The RVS uses a simple theory of reconfigurability to increase its capacity and productivity. The innovative design improves mineral particle screening through the inbuilt geometric screen structure, which ensures alteration of the screen surface structure so that adequate amounts of mineral concentrates can be screened. At first configuration the RVS operates same way as the conventional vibrating screen. As the production of mineral particles increases the screen is able to adjust to the required capacity. As the machine expand through the addition and subtraction. At its maximum configuration the screen exceeds the capabilities of a conventional screen with the same specifications. The RVS, exhibit principles of RMS such as scalability, modularity, and integrability.

3.2 Dynamic modelling of RVS machine

A finite model of the structure using normal Computer Aided Design (CAD) software is essential in order to determine failures caused due to uncertainty of loads applied Chuanguang *et al.* [30]. In this study, the structure of the RVS machine was analysed and connecting bolts were represented by means of point loads as ascertained by authors [31-32].

3.2.1 Mesh generation

The RVS machine structure was meshed with finer elements and also connected with various nodes between the elements; in order to enhance the accuracy of the FEA results as well as to lessen the computational time. Furthermore, the mesh was refined in the contact zones of the screen with other sub-systems as well as in areas of interests in order to produce more accurate stress results. The average value of the mesh size used in this analysis was 0.1 mm, resulting in 179 478 elements and 468 019 nodes as shown in Fig. 3.

3.2.2 Application of Material

Stiffness of the RVS machine structure is influenced by the geometry and mechanical properties of the structure. The CAD model already determined the geometry of the model, however there was also a need to specify the properties of the material to be used in the FEA analysis. The material properties of RVS machine structure were used in the FEA analysis as per the required application are shown in Table 2.

Table 2: Material properties for the RVS machine structure

No.	Parameter	Description
1	Material type	AISI 1020 Mild Steel
2	Yield strength	361.57 MPa
3	Ultimate tensile strength	420.51 MPa
4	Young's Modulus	200 GPa
5	Density	7900 kg/m^3
6	Poisson's ratio	0.29

3.2.3 Application of Loads and Boundary Conditions

The next phase after application of mesh and material is to specify the loads that will influence the operation of the machine as well as related boundary conditions. A uniformly distributed load, of the mineral particles that need to be screened on the machine was applied on the model developed was applied based on the weight of each mineral product that was screened over the entire RVS machine screen surface as depicted in Table 3 at the feed rate of 2 ton/hr.

Table 3: Load variations for different samples on the RVS machine structure

Material	Load (N)
Granite (crushed)	276.15
Coal	172.17
Iron	465.39
Chrome ore	437.23
Lime stone (ground)	170.99

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3.2.4 Applying Constraints

Without constraints, the model is free to float in space and there would be no deflections in the model. Therefore, a model is required to be constrained so that it is allowed to deform, but restricted from a rigid body motion in any of the coordinate directions. Another important step is the simplification and ease of representation of off-the-shelf components used on the machine which include in the overall assembly of the RVS machine structure such as bolts, motors and suspension units on the model developed. This simplification could be achieved by representing the motor with a point mass, while the bolts and suspension units can be represented by mathematical equations that depict the nature of the function on the structure as shown in Fig. 3.

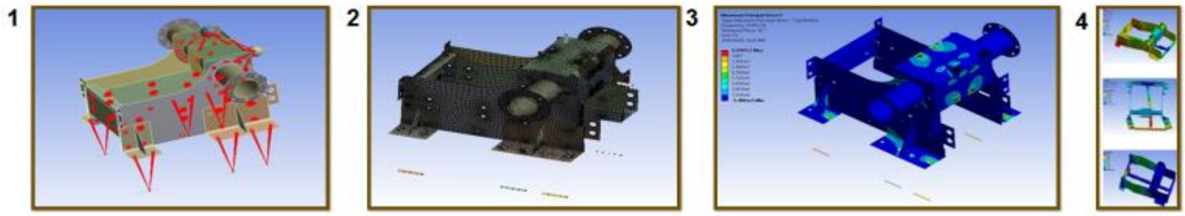

Fig. 3. Application of constraints on the RVS machine structure.

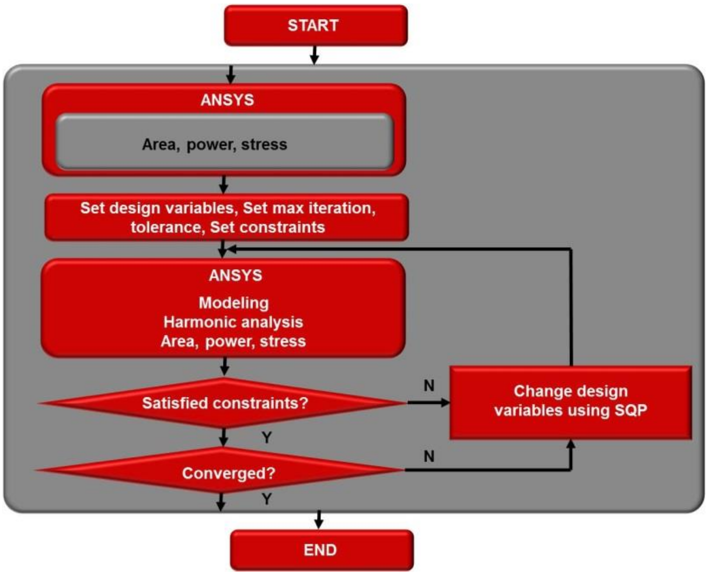

Fig. 4. Methodology for performing the stress analysis on the RVS machine.

3.3 Experimental procedure for the determining the performance of RVS machine

This section presents experimental work carried out during the performance evaluation of the RVS machine prototype. A 16-channel module analyser, was used to capture the signal responses via sensors during the operation. Furthermore, the paper established different parameter of interest under different working conditions using laboratory experiments. The step by step procedure used to carry out the experiments is presented below.

Step 1*: Selection of the material and devices needed for the experiment.*
Step 2*: Perform sample characterisation and preparation.*
Step 3*: Fitting and connection sensors to the machine and the DAQ for the machine performance condition monitoring.*
Step 4*: Feed the crushed mineral particle products on the surface of the screen and time the process accordingly.*
Step 5*: Analyse the results captured through the DAQ device and analyse the stress values recorded over time.*

Fig. 5 below present a schematic diagram of the experimental set-up consisting with the different materials used for this study.

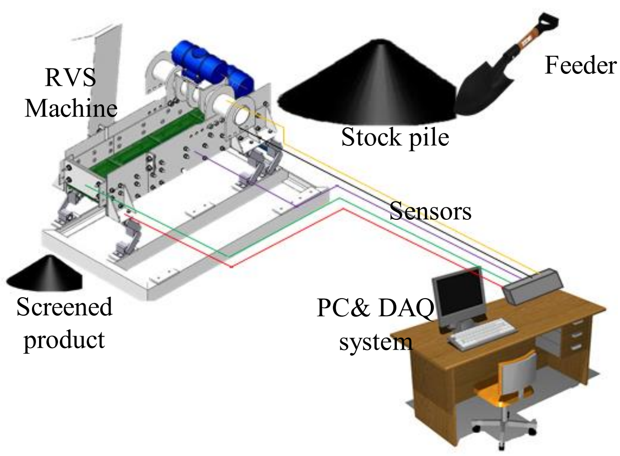

Fig. 5. Experimental set-up for RVS machine performance evaluation

4. Results and discussions of the stresses acting on the various subsystems of the RVS machine

The need for such structural improvements is closely associated with the type of loads imposed to that particular area of interest as well as the application there of. The results imply that stress concentration may arise on the interfaces of the side plates and may further spread to other area of the RVS machine structure if used continuously during screening. Thus, interventions are required to avert these issues from occurring. The next section presents the results of the critical threshold obtained from the FEA analysis.

4.1 Results of the critical stress thresholds obtained from the dynamic simulation analysis

For the 1st RVS machine configuration, the maximum stress of 16 MPa was experienced by the back plate assembly, followed by the stringer with the maximum stress of 15 MPa when the machine is loaded with granite. On the other hand, for the 2nd RVS machine configuration, the maximum stress of 24 MPa was experienced by the side plate assembly when iron ore is loaded, in addition the same side plate assembly showed maximum stress of 21.7 MPa when the machine is loaded with gold ore. Lastly, for the 3rd RVS machine configuration, the maximum stress of 22 MPa was experienced by the drive beam assembly when iron ore is loaded, moreover the drive beam assembly again showed maximum stress of 21.8 MPa when the same material.

4.2 Results of stress values using strain gauges

The results of the experimental study indicates that the current stresses that the RVS machine subsystems are subjected to during the granite screening operation, which are 4 3.9 MPa, 16 MPa, 40 MPa, 12 MPa and 15 MPa, respectively as determined through experiments. This implies that the RVS machine will still be able to operate under normal condition and its subsystems will not experience failure. In addition, it means that mining machine managers should always be alert not to over load material on the RVS machine as this would increase the stress values beyond the critical threshold.

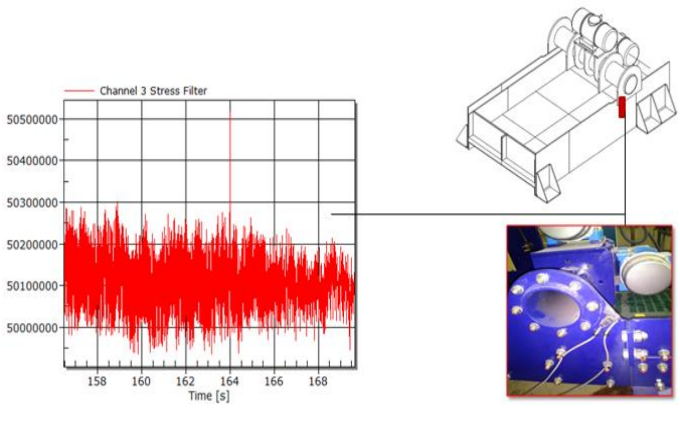

Fig. 6. Stress vs time results of the RVS side-plate component.

4.3 Comparative analysis between FEA and experimental results

In this section, the theoretical and experimental stress distribution values are compared to each other as shown in Table 4. Any significant and minor deviations are discussed in order to determine the source that lead to the changes. Regardless of the side plates showing the highest stress concentrations compared to other RVS machine subsystems, the drive beam assembly is still considered the core of the RVS machine systems, due to the fact that it holds the rest of the structure in a stable position and holds the drive excitation motors which ensure efficient movement of particles across the surface of the screen.

Table 4. Comparative analysis of simulated stress vs experimental results

RVS machine subsystem	Experimental stress (MPa)	Stress simulations (MPa)
Subsystem I	3.9	4.5
Subsystem II	16	16.4
Subsystem III	40	21.2
Subsystem IV	12	15.6
Subsystem V	15	8.0

An experimental study carried out by Zhang *et al.* [33] proved that a realistic reduced scale model of a vibrating screen machine can substitute the prototype vibrating screen for modal testing analysis, which can provide a shortcut to structural modification and substructure coupling analysis of the prototype of the large vibrating screen. In this study a functional prototype of the RVS machine was build using similar specification as computed in the ANSYS® software in order to ascertain the accuracy of the results obtained through simulation and experiments. The final prototype machine of the RVS is presented in Fig. 7.

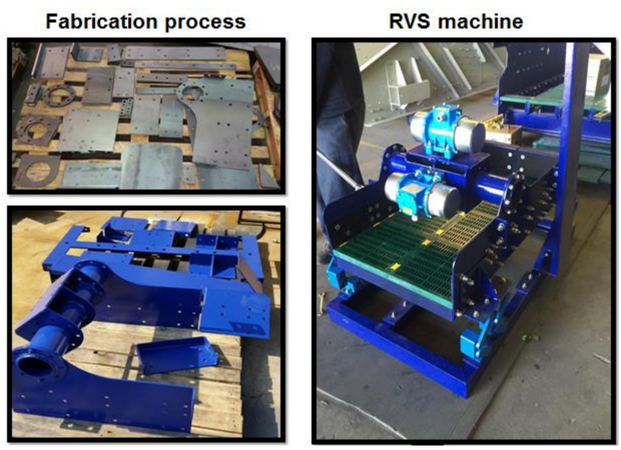

Fig. 7. Fabrication process for RVS machine.

4. Conclusions and discussions

The increasing demand of mineral concentrates products in the mining and mineral processing industries has called for the design of new innovative machine solutions capable of addressing this inevitable scenario affecting the mining

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organisations. Vibrating screens are one of the most important machines used in mining and mineral processing industries to ensure beneficiation of mineral products into various sizes and grades. However, there is a greater risk facing these industries in utilizing these machines to meet fluctuating mineral concentrates demands. Thus, this study proposes and evaluates the performance of innovative beneficiation equipment called "reconfigurable vibrating screen" that could be used to screen different mineral particle sizes and volumes demanded by the customers in a more cost-effective manner. The results of the analysis showed Subsystem I, Subsystem II, Subsystem III, Subsystem IV and Subsystem exhibited theoretical stress of 4.5 MPa, 16.4 MPa, 21.2 MPa, 15.6 MPa and 8.0 MPa, while the experimental stress values of 3.9 MPa, 16 MPa, 40 MPa, 12 MPa and 15 MPa, respectively deviate slightly from each other as determined.

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