On shale shaker’s structural optimization and performance improvement

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Abstract. Recent trends, predictions [1] and overall assessments [2] in extractive industries show there will be changes in many aspects of business, varying from geopolitical issues up to the optimization of working processes and machines. In severe conditions of drilling stations usually based quite a way off to cities and are difficult to access, it is important for all the equipment and machines to operate without failure and provide forecasted level of durability, because unexpected shutdown may lead to halting of production and economic losses. This article is focused on investigation of shale shaker primary characteristics and its behavior during operational loads. In the result of the work an optimization has been performed on the basis of kinematic, strength and NVH performance. Special emphasis was put on the value of vibrational acceleration which reflects an overall possibility of a shale shaker to sift drilling mud. It is a widespread practice to implement optimization tools into different fields. The methods of usage topology optimization can follow the same ideas as it is done in automotive [3] or agricultural industries [4]. Advantage of this paper based on intense cooperation between manufacturing department of the customer and CAE engineers which is the basis of a good design process [5] and overall approach to successful development [6], that includes manufacturing restrictions and that allowed to prove sustainability of the models through validation phases, in the beginning of the project for the initial structure and in the middle of the project for several newly assembled prototypes. So the results of the work have been confirmed by real experiments. Another strong point was a possibility to obtain a feedback right from drilling stations about the condition of optimized shale shaker after it started to work under common operational loads. Constant monitoring, predicting systems and other methods to evaluate overall condition of the machines under operational loads or drilling fluids [7] during the extraction process are important measures in order to prevent unexpected failures. Process and result of this work can be assembled in a step-by-step method for simplified evaluation of shale shakers with vibrators of different amounts and powers. Such method allowed to obtain an overall glimpse on main characteristics, performance, to locate durability weak zones and shows potential for possible structural optimization. The new approach has been used in this research by using the CML-Bench platform, which is a system for managing the simulation driven design projects field of digital design and modeling [8]. This system allows tracking and observing all necessary variables, simulation history and mutual influence of different parameters on different structural changes. Such a method for design engineering allows easily carrying out multidisciplinary optimization of the objects and always being aware of the performance state of the whole system [9].
1. Introduction
Shale shakers belong to the components of the mud handling system and are used to separate large solid particles from drilling fluid. On high level main parts of the shale shaker are vibrator, screen basket with angling mechanism, feeder and base [10].
An interfusion of muck, drilling fluid, ground and other solid particles come from the borehole to a collection pan called feeder and then transferred to the shale shaker screening area which is essentially responsible for shaking and sifting [11]. Such behavior is caused by the work of vibrators which provide necessary load to the shaker bed.
One of the most important values which characterize an intensity of shaking is called vibrational acceleration and measure in G’s. It is assumed higher values of G’s provide more effective process of sifting.
Some investigations in the area of performance improvement are based on using different kinds of screen, separators and types of drilling liquid [12]. This article is focused on structural changes of the shale shaker bed.
In most cases two vibrators with linear motion is used, however some machines have an additional option of adding a third motor providing elliptical motion, so an overall motion of the basket tends to be more circular and softer. This kind of motion always decreases an overall value of G and is used depending on the consistence of the fluids from the drill or customer specific requirements.
The main goal of this paper was to increase maximal vibrational acceleration of the shale shaker while keeping structural performance, design feasibility and cost at the same level. Using different amount of vibrators or different engine powers is an obvious option to increase the result, so in addition a structural optimization and mass reduction of the shale shaker vibrating bed has been performed in order to increase G. Though shale shaker is a relatively easy to be controlled in terms of drive system [13], in this investigation it was important to suggest sustainable from the performance and possible from manufacturing point of view structural changes of the shale shaker.
A layout of a conventional shale shaker is depicted in the figure 1.

Figure 1. Shale shaker layout.

2. Project guidelines
In order to make an overall estimation of the structure the following steps has been proposed and performed by the authors for the optimization process:
1) Creation of MBS model on the basis of actual CAD-Data, vibrator properties and mass distribution of all relevant components
2) Simulation of idle motion operational state of the shale shaker. Vibrational acceleration and displacement estimation.
3) Validation on the basis of real tests and model confirmation
4) Obtaining maximum load values from fixed shale shaker base to the spring mounting points and from vibrators to the vibrator support
5) Static strength evaluation using maximum load values from MBS model
6) Durability evaluation using load history from MBS model. Weak areas determination
7) Global stiffness and frequency evaluation
8) Structural changes of the shaking bed

All necessary steps have been repeated after every optimization loop in order to track the influence of structural changes or vibrator parameters on overall behavior of the shale shaker.

Following software has been used during optimization process:
1) MBS analysis in MSC Adams
2) NVH, strength and durability in MSC Nastran

First step was to create an MSB model of the shale shaker and perform kinematic simulation of the idle motion [14]. MBS model of the shale shaker with three vibrators is shown in the figure 2.

![MBS Model](image)

**Figure 2. MBS Model.**

In order to ensure model sufficiency, a validation has been performed on the basis of initial shale shaker structure. Comparison of the results between initial digital model and real test are shown in the table 1.

| Linear operating mode | Linear-elliptical operating mode |
|-----------------------|----------------------------------|
| Maximal vibrational acceleration, G | Maximal vibrational displacement, mm |
| Maximal vibrational acceleration, G | Maximal vibrational displacement, mm |

| Difference, % | 4.1 | 0 | 1.89 | 2.59 |

**Table 1. Initial model validation.**

Initial MBS-Model showed high correlation between real tests in terms of measurement of vibrational acceleration and displacement, both on linear and elliptical operating modes and could be regarded as sustainable.
3. Overall performance and optimization
After that a series of calculations have been performed on the basis of validated kinematic analysis. Using results from MBS analysis, loads have been applied to the spring mounting points and vibrators mounting points to estimate static strength, stiffness, frequencies and durability. Boundary conditions for corresponding loadcases are shown below. For static strength load points with corresponding maximal forces are marked with red dots.

Figure 3. Static strength.
For torsional and bending stiffness corresponding boundary conditions and loads have been applied in the following way.

**Figure 4.** Torsional stiffness.

**Figure 5.** Bending stiffness.

All above mentioned loadcases have been calculated along with modal and kinematic analysis for initial and optimized structures with different types of vibrators. As result of the work, three variants of optimized shale shakers vibrating beds have been proposed to the customer. Optimized variants contained new set of thicknesses and shapes of main transversal and longitudinal parts.
4. Optimized structures

Optimized structure №1 contained general proposals based on parametrical optimization of parts of shale shaker, didn’t require any changes from manufacturing point of view and didn’t increase complexity of assembly.

Several prototypes of this proposal have been assembled and tested by the customer during the project phase for another round of model validation. Results of comparison are depicted in the table 2 below.

| Different between virtual results and real tests | Linear operating mode | Difference with prototype 1 | Difference with prototype 2 |
|-------------------------------------------------|-----------------------|-----------------------------|-----------------------------|
|                                                 | Maximal vibrational acceleration, G | 2.12%                      | 3.06%                      |
|                                                 | Maximal vibrational displacement, mm | 0.44%                      | 1.76%                      |

Results of validation between virtual model and real tests showed high correlation and even better convergence in comparison for initial model validation.

Optimized structure #2 was based on the variant №1 and contained additional proposals based on topology optimization of parts of shale shaker. This proposal didn’t require any changes from manufacturing point of view, however at some extent increased complexity of assembly and working operations. This proposal has been accepted by the customer for as a modification for mass production.

Result of one of the proposals for cut outs on the motor mount is depicted in the c 6. Red lines represent main load paths to bear the load from the motors.

![Motor mount topology optimization results](image)

Optimized structure №3 contained significant structural changes, required changes from manufacturing point of view, however at some extent increased complexity of assembly and working operations. This proposal has been also accepted by the customer for theoretical possibility of production upon updating manufacturing line.

An overview comparison table with the results of initial structure is depicted in the table 3.
Table 3. Results of initial structure is depicted.

| Comparison with initial structure | Kinematic | Stiffness | Modal | Durability | Weight |
|----------------------------------|-----------|-----------|-------|------------|--------|
|                                  | Maximal vibrational acceleration, G | Maximal vibrational displacement, mm | Torsional | Bending | First natural frequency, Hz | Life cycles | Mass, kg |
| Optimized structure №1           | +4.3% (+0.35G) | +4.5% | +69% | +8.5% | -4% | No failure | -10% |
| Optimized structure №2           | +12.9% (+1.05G) | +15% | +76% | -1.5% | -2.2% | No failure | -16.6% |
| Optimized structure №3           | +24.8% (+2.02G) | +25% | +116% | +0.3 | -3.3% | No failure | -19.2% |

5. Additional calculations
In order to get a more realistic influence of a load coming to the motor from drillhole liquid and particles an explicit process this behavior has been calculated, based on the data of an average particles dimension and density which usually travel through the shaking bed. Result of simulation process is depicted in the figure 7.

Figure 7. Explicit process of particles distribution.

A series of additional calculations have been performed to locate weak zones in terms of durability. To estimate influence of material thinning or its properties degradation, assembly imperfections, different ways of vibrator mounts positioning and several versions of mobile modifications for shale shakers.
One of customer existing and operating shale shaker modifications suffered from fractures in the area vibrator mounts. After performing kinematic simulation and fatigue estimation most dangerous zones have been observed, which have been located at the same areas as in the figures provided from the customer. Result of simulation and comparison with real photos are depicted in the figure 8.
Figure 8. Result of simulation.

A simple coupling from kinematic analysis to fatigue calculation allowed to observed zones, tend to have stress concentrations.

6. Conclusion
As a result of the work more than 100 modifications have been investigated for all abovementioned loadcases. An optimized structure showed higher G value while keeping the rest of performance at required level.

A series of step-by-step calculations allowed to assemble results of the work into a method for performance and durability estimation of shale shakers of different modifications.

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