VACUUM DISK FILTER: FAILURE STUDY AND SEARCH FOR IMPROVEMENTS USING A SYSTEMATIC DESIGNING APPROACH

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Abstract. *During the process of ore processing, the use of water is fundamental to the execution of some steps; a pulp is created among the mixture of elements. In order to withdraw the humidity of the ore after its processing filters are used. Lately, in order to treat iron ores, the mining industries are using, mainly, vacuum disk filters, due to their low implantation cost and large are of filtering for installation space. A large number of failures on the sustaining rods of the filtering disks are happening. The goal of this article is to study this failure using design methodology for industrial products and finite elements analysis. During the filtering cycle the sustaining rods are subject of alternating loads. Based on the method of calculating floating stresses, it was noted that the failure happens due to fatigue. In order to improve the fatigue strength limit and eliminate systematic failures a new design for the sustaining rod was developed with the objective of augmenting the number of life* *cycles and guarantying a larger productivity and lowering the maintenance breaks on the equipment.*

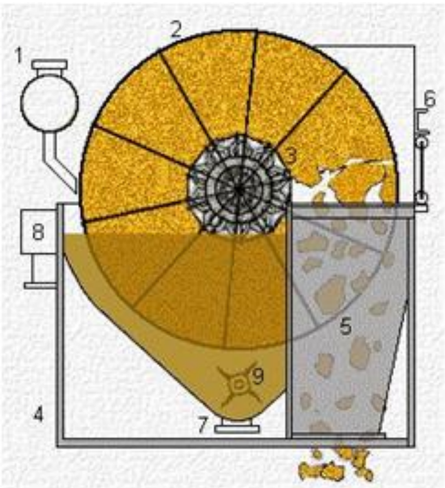
Keywords: *Ore processing industry, Fatigue, Failure study, Vacuum disk filter, Finite element analysis*

1 INTRODUCTION

This article presents a study of the conception of improvements for vacuum filter disks utilized in one of the steps of ore treatments, through a systematic approach of the design. The focus was the analysis of the failures on the sustaining rods of the filtering disks, using tools of failure analysis study methodology of industrial equipment, producing an systematic approach for the analysis of technological alternatives and economic viable, in order to improve the reliability of the sustaining rod.

In order to validate the analysis, to prove the failure by fatigue on the equipment, the commercial finite elements software, ABAQUS, was used, based on the results of the mathematical models of the fatigue failure criteria for floating stresses, according to the Geber parabola and the line of Soderberg. The rods have a 24 mm diameter and are 1100 mm long, made of steel SAE1045. The function of those supporting rods are to sustain the filtering disk composed of the sectors of filters, sustaining clamps and the filtering elements. The failure of this component, leads to damage in the filtering disk elements causing the break of the equipment, compromising the profits due to losses in production, accidents and environment aggressions.

This filter is composed of a tub where the ore pulp is deposited, over that tub there is shaft where the disks are mounted, composed, in general, of 10 sectors of polypropylene, that are sustained by the fixing rods. In the beginning of the process the material is deposited on the tub through the feeding box, the filtering occurs through capillary action of the vacuum, which drains the water and retain the solid in the filtering tissue, creating the “pie”. The formation of the “pie” occurs when the filtering tissue contacts the pulp in the tub. The capillary action creates vacuum that sucks the liquid present in the pulp and accumulates the solid in the filtering elements. When the material is agglomerated on the filtering tissue, the instant with the most load on the supporting rod happens, for it is loaded and still needs to complete the cycle when the pulp leaves the tissue. Figure 1 represents a vacuum disk filter during the filtering process (BRASFELT, 2013).



1-Pulp feeding
2-Disks and sectors
3-Tree
4-Tub
5-Discharge kick
6-Washing system
7-Tub drain
8-Over Flow
9-Agitator

Figure 1. Vacuum disk filter

Failures are occurring on the support rods due to the loads acting on them, their rupture leads to a series of damages on the equipment generating production losses, considering the hour of stopped equipment, maintenance cost and damages caused by this failure. A simple part, with a low cost compared to the cost of the machine, becomes something critical, relevant and deserving of an insightful technical study. The analysis of the failure of the supporting rods of the filter sector allows the evaluation of technical alternatives for the definition of feasible corrective actions for the system, increasing the equipment reliability.

2 PROCEDURE

The present article consists of the failure analysis of a vacuum disk filter, more specifically on the supporting rods, which fractures after a time of operation and on breaking, the filtering process halts, due to a stoppage of the machines.

Initially, a failure analysis was studied on the supporting rod; to identify the origin of the failure. After finding the source of the failure, a finite elements analysis was done to support the utilized methodology. After finding the source of the failure, a new design was proposed in order to correct the identified problem. Calculations using the new design parameters and a new finite elements analysis were done in order to verify the cohesion of the results.

2.1 Failure analysis

The study to find the source of the failure aimed to increase the life span of the supporting rods during the separation between solid and liquid in one of the steps of ore processing and to maximize the productivity by minimizing the interventions for maintenance.

The main goal of a failure analysis is to discover the basic causes of the equipment failure. After the failure analysis is done, every information collected must be utilized, to determine the corrective actions in order to avoid the recurrence of the problem, increasing the reliability of the equipment.

According to Affonso (2006), a component of an equipment have failed when he is unable to execute his function with safety. The concept of premature failure is applicable if the failing occurs during the estimated lifecycle of the component. This lifecycle must be defined as a design criterion and associated with a specified failure mode.

2.2 Fatigue failure

According to Callister (2006) fatigue is a term used to express the mode of failure that occurs in structures or in machine parts, when they are under repeating, alternating or fluctuating stresses. It happens under the actions of cyclic loads and under those circumstances, the failure occurs in stress levels way under the ultimate tensile strength of the material or even the yield strength, when it is submitted to a static compression or tensile tests. The method used to estimate the failure by fatigue and the proposal to increase the lifecycle of the component, had as criteria, the fatigue failure study for fluctuating stresses and the alteration of the diameter and quality of the material.

2.3 Finite elements analysis

The computational methodology was based on the finite elements method, with the determination of the element type to be utilized, the mathematical model, the discretization and analysis of the results, as well as the examination of the model and its parameters.

Initially the mathematical model of the supporting rod was generated using the ABAQUS software as shown by Fig. 2, with real dimensions, the material used was the steel SAE-1045.

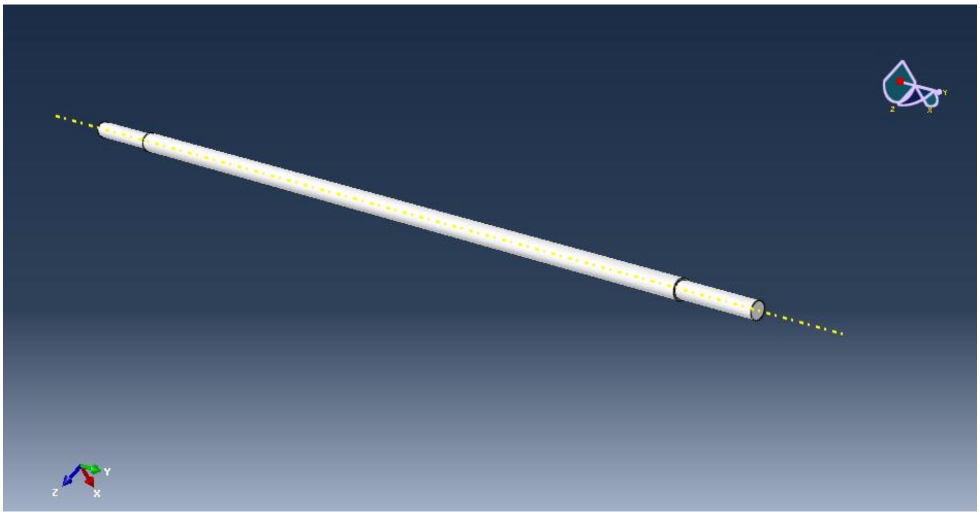


Figure 2. Model of the supporting rod

In order to discretize the model 8 nodes 3D linear solid elements were utilized (C3D8). The finite elements meshing was generated as shown by Fig. 3, containing 10965 nodes and 8935 elements of average size of 5 mm. Before generating the mesh, tests were executed applying the loads and varying the elements sizes. The value of 5 mm presented the better results.

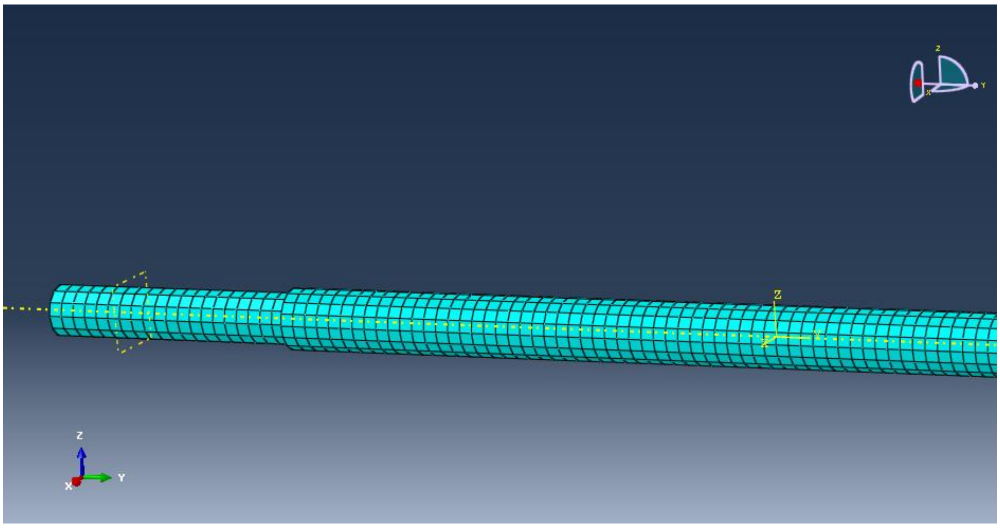


Figure 3. Finite elements meshing

The loads were applied and the contact area of the screw was constrained with 0 degrees of freedom on the X,Y and Z axis. Figure 4 presents the loads applied in their respective positions.

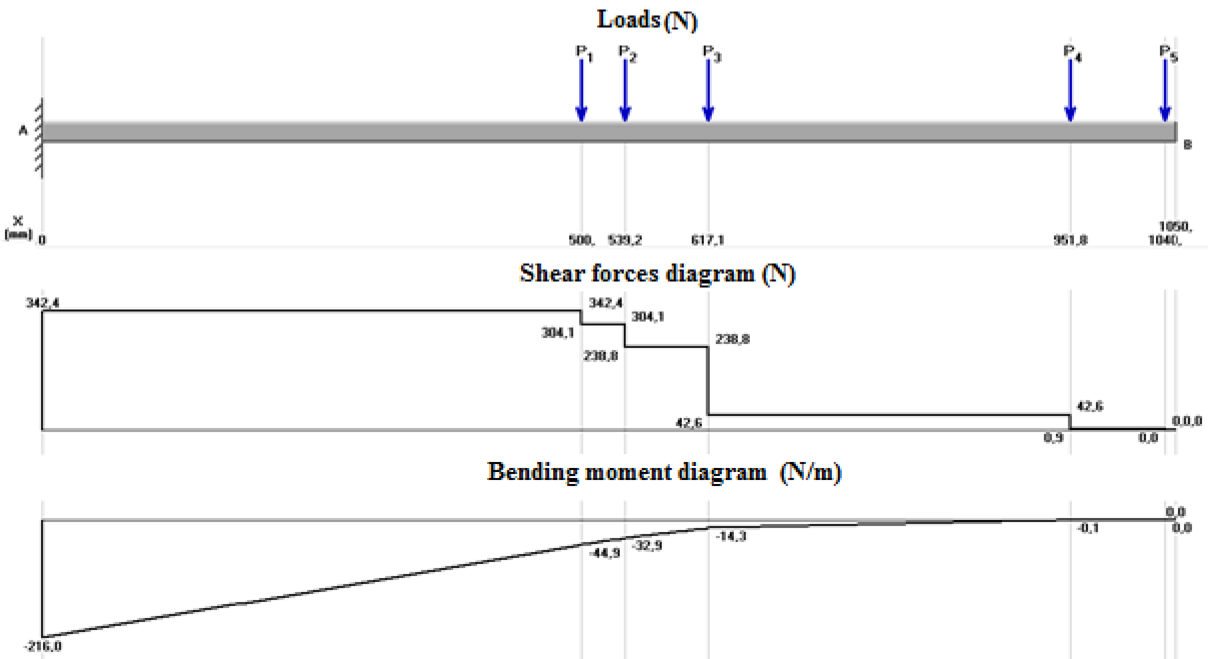


Figure 4. Load distribution on the supporting rod

Figure 5 shows the maximum principal stress of 244.2 MPa.

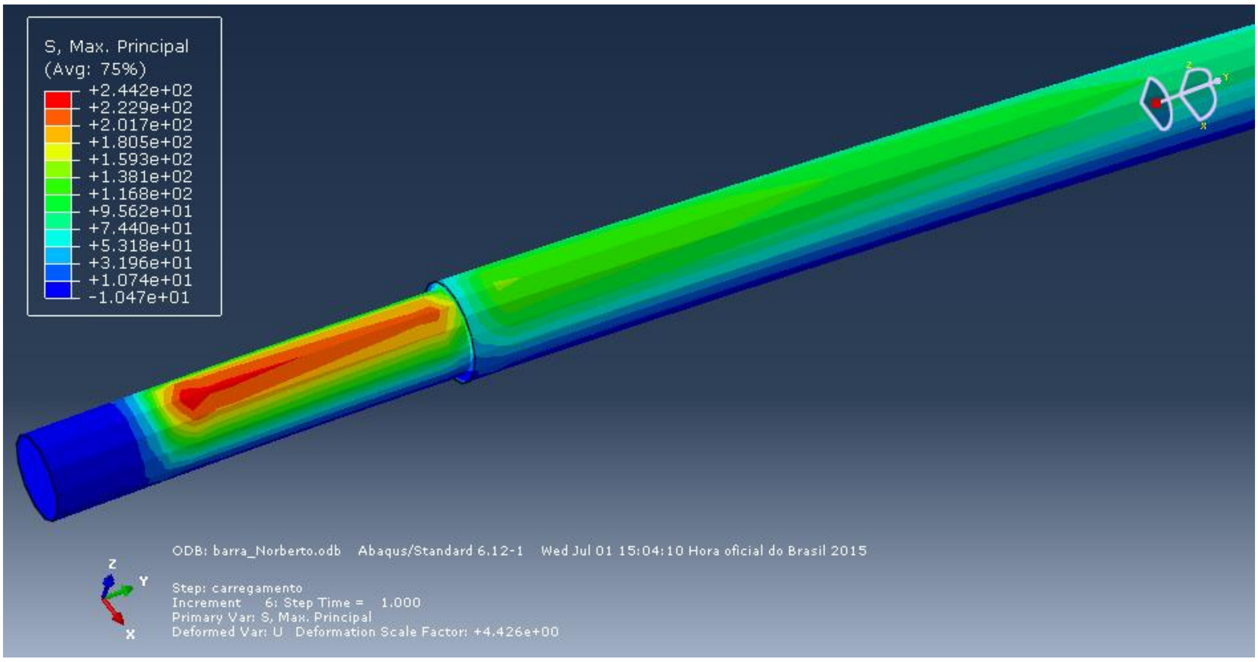


Figure 5. Maximum principal stress

2.4 Fatigue analysis and life cycle

The first step for the determination of the number of cycles before failure for the supporting rod under the acting loads was the use of the fluctuating stresses method, according to criterions of Soderberg and Gerber. Using Shigley (2005) presents Eq. (1) using Soderberg's criteria:

$$\frac{\sigma_{alt}}{Se} + \frac{\sigma_{med}}{\sigma_y} \leq 1 \ . \tag{1}$$

The calculated value on the left side of the equation was 1.55, according to Soderberg's criteria the supporting rod may fail.

Equation (2) presents Gerber's equation according to Shigley (2005):

$$\frac{\sigma_{alt}}{Se} + \left(\frac{\sigma_{med}}{\sigma_r}\right)^2 \leq 1. \tag{2}$$

The calculated value on the left side of the equation was 1.55, according to Gerber's criteria the supporting rod would fail.

The S-N diagram can be obtained using the effective stress and the mean stress for 10^3 cycles. According to Norton (2004) can be calculated by Eq. (3):

$$\log\left(S_{efetiva}\right) = \log(a) + b\log(N). \tag{3}$$

The values for a and b can be calculated using Eq. (4) and Eq. (5) respectively:

$$b = -\frac{1}{3}\log\left(\frac{S_m}{S_e}\right). \tag{4}$$

$$\log(a) = \log(S_m) - 3b\,. \tag{5}$$

The number N of cycles was calculated as being 892.8. Figure 6 shows the S-N diagram of the supporting rod,

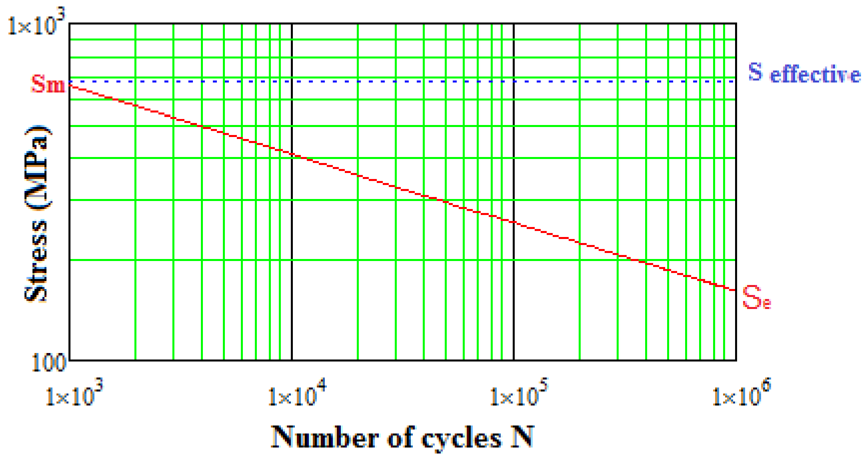


Figure 6. S-N diagram

2.5 Proposal of technical changes

After finding the fatigue failure on the supporting rods happening after a relatively low number of cycles, it becomes necessary a technical change on the design to better adequate and size the equipment to its function.

The supporting rods musts respect the constraints in diameter and length necessaries for the fitting in the section with the filtering tissue, that is imported and of a higher cost, therefore it is of interest to keep the same dimensions of the former equipment. A direct way to increase the mechanical attributes of the supporting rod is the utilization of another material, so, the use of the steel SAE-4140 was analyzed for having a relatively better mechanical behavior with a competitive market value if compared to the steel SAE-1045.

A comparison between the materials can be seen on Table 1.

Table 1. Comparison between SAE-1045 and SAE-4140

	Current	Proposed
Material	Steel SAE-1045	Steel SAE-4140
Ultimate Tensile Strength	650–800 MPa	1,000–1,200 MPa
Yield Strength	Min. 430 MPa	Min. 750 MPa
Elongation	16%	11%

Another way to improve the design is to change the sizing of the screw, aiming to decrease the effective stress acting on the component, which according to the finite elements analysis and empirical evidence; it is the region with the most probability of failure. Table 2 shows the proposed alterations for the sizing of the screw.

Table 2. Sizing alteration on the screw

	Current	Proposed
Cylindrical bar	ø 24	ø 25,4
Cross section area	452.38 mm^2	506.71 mm^2
Screw size	M24	M27
Screw center diameter	ø 20.32	ø 23.32
Screw cross section area	324.29 mm^2	427.12 mm^2

A drawing for the manufacturing of the proposed supporting rod is presented on Fig. 7, a round cold-drawn beam made of steel SAE-4140, total mass of 4.37 kg.

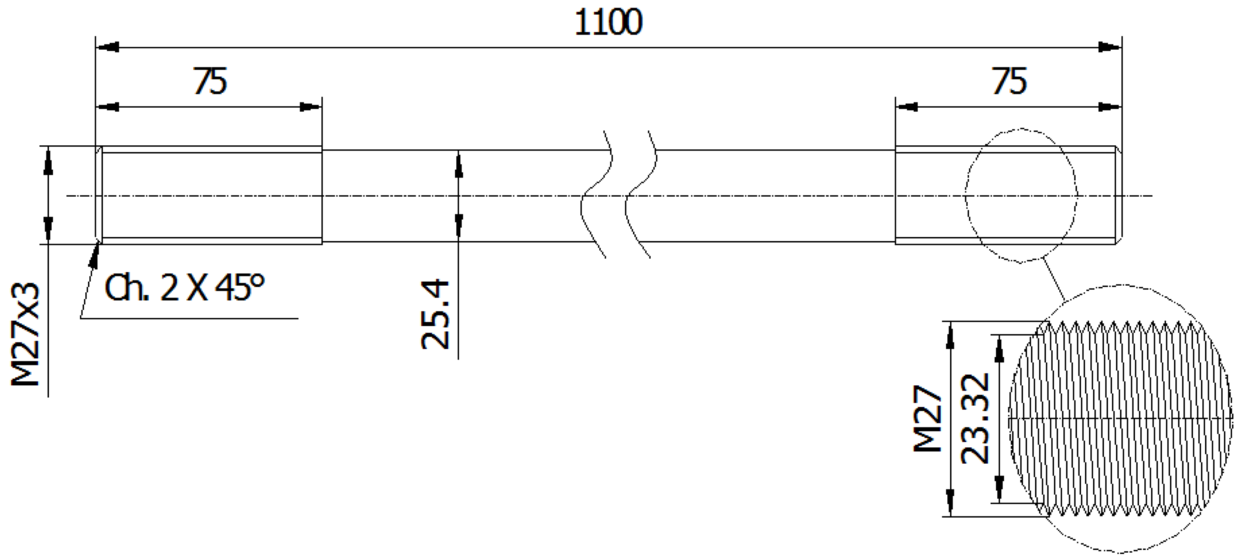


Figure 7. Drawing of the proposed supporting rod

3 RESULTS

A second failure analysis was done on the supporting rod with the proposed technical changes using the same method presented previously, a value found for the fatigue strength was173.1 MPa.

A second failure analysis using the fluctuating stresses criteria considering the Soderberg and Gerber curves was done. Values for the mean stress and alternated stress were calculated respectively as being 0 and 126.7 MPa.

Applying the Soderberg method a value for the left side of Eq. (1) was 0.73, therefore, according to the criteria, the supporting rod should not fail. Similarly, applying the Gerber method shown on Eq. (2), a value of 0.73 was found for the left side of the equation, hence, the supporting rod should not fail.

Subsequently the effective stress on the proposed supporting rod was calculated, having a value of 418.2 MPa, the mean stress was also found with the value of 990 MPa. A new S-N diagram was traced for the supporting rod, as shown by Fig. 8.

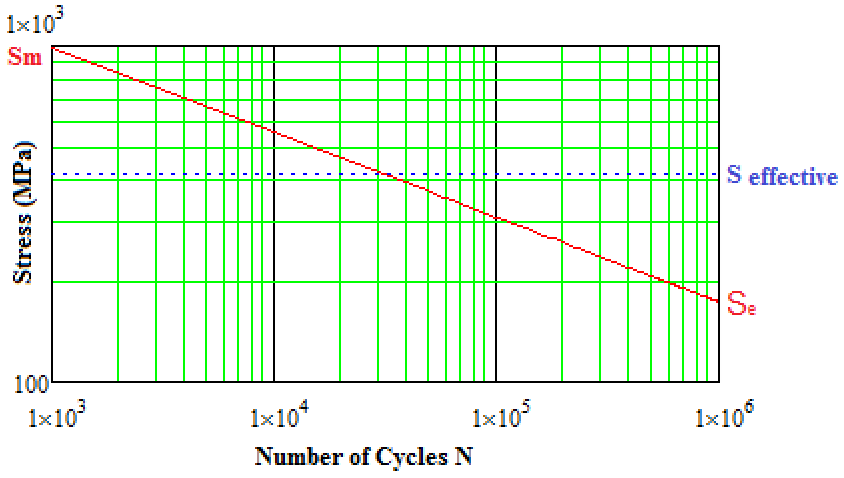


Figure 8. S-N diagram

The number of cycles for the proposed supporting rod was calculated as N = 30,376.3 using Eq. (3).

The computational methodology was done once more using the same modeling parameters, choice of elements and pre-processing, and using the parameters of material and size of the proposed supporting rod. The finite elements meshing was generated, creating 11,886 nodes and 9,815 elements of average size of 5 mm. Figure 9 shows the supporting rod modeled on ABAQUS with its changed geometry and made of steel SAE-4140.

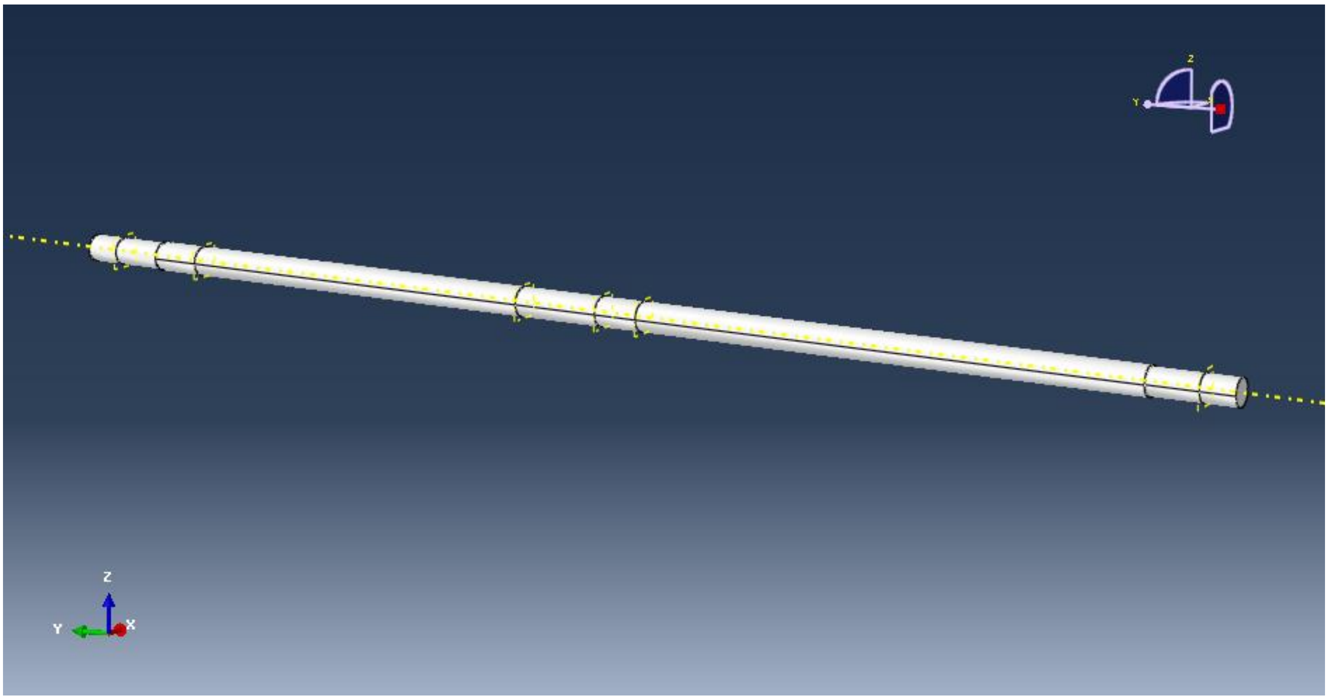


Figure 9, Model of the supporting rod

Figure 10 shows the maximum principal stress of 155.9 MPa, value significantly lower than the one found in the analysis of the supporting rod before the material and size changes.

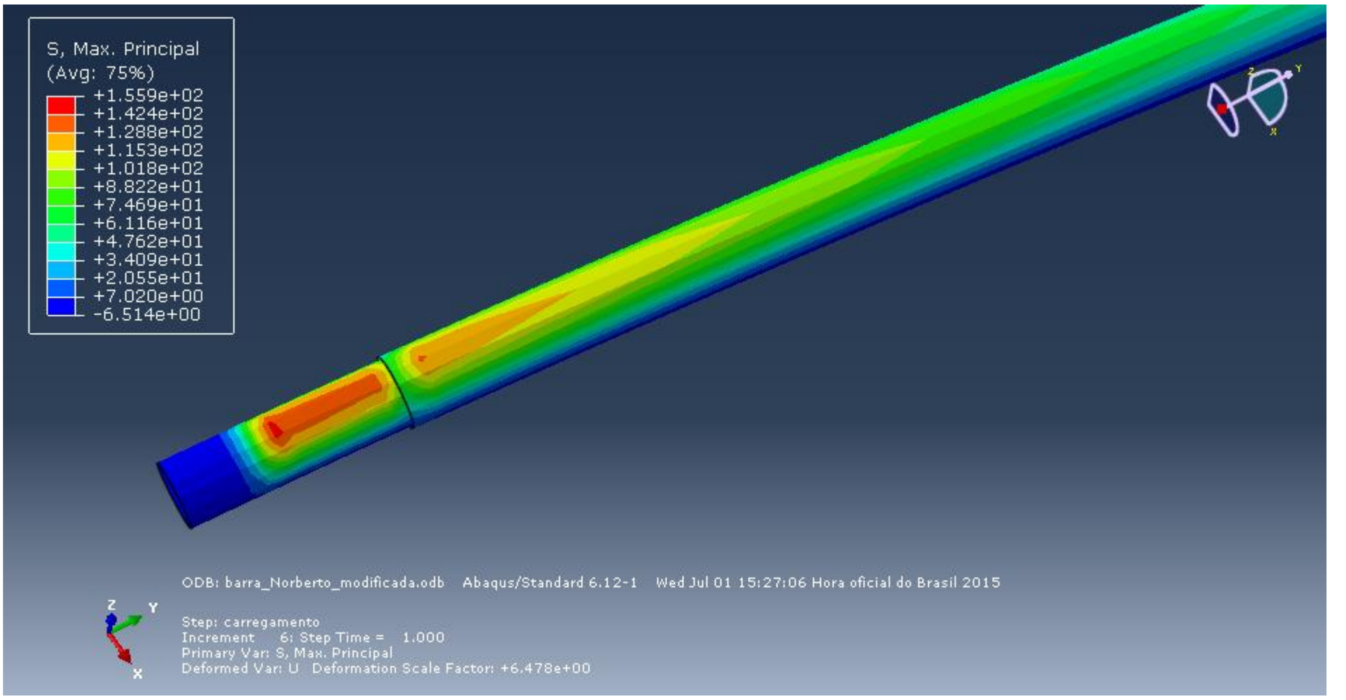


Figure 5. Maximum principal stress

4 CONCLUSIONS

According to the analysis of the S-N diagram, it can be stated that the proposed design will increase the number of cycles from 892.8 to 30,376.63. The fatigue failure may occur at a high number of cycles, which will provide an improvement of the lifespan of the equipment, reducing the number of interventions to substitute the supporting rods where the failure occurs.

Table 3 presents the comparison between the current situation and the projected one. This comparison shows the evolution of the number of cycles, the effective stress and the fatigue limit due to the change of material and size of the part. Based on the data it can be concluded that the proposed supporting rod will have better results than the supporting rod current in use, having a lifespan compatible with the expected from the equipment design, elimination systematic failures on the supporting rod.

Table 3. Comparison between currently used and proposed supporting rod

	Current	Proposed	Variation
Material	Steel SAE-1045	Steel SAE-4140	
Ultimate tensile strength	650–800 MPa	1,000–1,200 MPa	

Yield strength	Min. 430 MPa	Min. 750 MPa	
Elongation	16%	11%	
Cylindrical bar	ø 24 mm	ø 25,4 mm	5,83%
Cross section area	452.38 mm^2	506.71mm^2	12%
Screw size	M24	M27	
Screw center diameter	ø 20.32mm	ø 23.32mm	14,76%
Screw cross section area	324.29mm^2	427.12mm^2	31,71
Fatigue strength	160.5Mpa	173.1MPa	7,8%
Effective stress	667.7Mpa	418.2MPa	37,4%
Soderberg failure criteria	1.55>1	0.73<1	
Gerber failure criteria	1.55>1	0.73<1	
Number of Cycles	892.8	30,376.3	

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