Designing and Simulation a Centrifugal Pump Shaft with Enhanced Mechanical Properties During Backpressure

P.B. Sob
Departmentof Mechanical Engineering, Faculty of Engineering and Technology, Vaal University of Technology, Vanderbijlpark 1900, Private Bag X021, South Africa

peterb@vut.ac.za

M. Pita

Department of Mechanical Engineering, Faculty of Engineering and Technology, University of South Africa.

pitam@unisa.ac.za

Abstract

several failures in centrifugal pump shaft are reported due to backpressure leading to unpredicted shaft failure during pump operation. several attempts have been made by engineers in designing and simulating a centrifugal pump shaft that can offer more enhanced mechanical properties which can withstand backpressure during operation. In this paper, a centrifugal pump shaft with more enhanced mechanical properties is designed to withstand backpressure. This is achieved by simulating the relevant parameters of stress-strain which impacts the system during backpressure. In the current study, an Auto desk fusion 360 was used to simulate the design shaft relationship of stress and strain parameters on back pressure intensity. During simulation, the centrifugal pump shaft was constrained on a drive end bearing and a non-drive end bearing by using frictionless constrain parameters at extreme back pressure during operation. The following facts were theoretically revealed after simulating the system with an Auto desk fusion 360 simulation software. It was observed that, there is extremely low possibility of shaft failure at the keyway slot section and the propagation of failure were invisible in this section of the shaft. When the shaft was subjected to severe stress and strain due to high intensity of backpressure, the material experiences fatigue and the fatigue zone start propagating leading to material defects and failure that were visible observed across the shaft during operation. However, the designed shaft was able to withstand high stress/strain during operation as the new yield stress increases to 207 MPa. The designed simulated shaft was revealed to withstand the subjected backpressure from the system and the possibility of material failure during pump operation was minimize.

Keywords: Design, modelling, stress, strain, centrifugal pump, and backpressure

1. Introduction

To design a stable centrifugal pump shaft, it is imperative to model the stress and strain factors that impacts the shfat during operation. Most of the time, it is vital to look at the shear stress theory (M.S.S.T) and stress-strain distribution of the shaft during backpressure process as these are vital parameters used in predicting a shaft failure mode during operation. The maximum shear stress and strain theory of a shaft is also termed as Guest and Tresca's theory and this theory are mostly used in elongated or ductile materials (Abdul, 2019). The theory of shear stress, strain and strain rate in a centrifugal pump shaft must be investigated if a stable and efficient shaft must be design. Most often, the failure mode of a centrifugal pump shaft due to back pressure are reported to occur when the maximum value of shear stress, strain and strain rate developed by the system exceeds designed shear stress, strain and strain rate during operation. It is reported that if maximum shear stress or strain developed by the system during backpressure exceeds the designed shear stress or strain the shaft can withstand the system is subjected to a failure mode.

Shear stress and strain in a system is a measure of the force per unit area being subjected to the system through the point of interest in the material during operation (Richard Leach, 2018). Strains define a new physical quantity and the stress being directly proportional to the strains display a distortional energy failure theory and, in most cases, this is called the effective stress or the Von Misses stress. During operation, Failure can be predicted due to distortional energy stored in the shaft material which is normally when and when the effective stress or von Misses value gets to yield stress. At this point material fatigue and failure are being reported during operation and cracks that propagates are more visible during operation (Akin, 2009). This could be analyzed from distortional theory that caused migration of grains at different curvature that leads to more cracks propagation at lower curvature than at higher curvaton due to dislocation motion and grain boundaries migration process that takes place in the material. In the current study, the theory of failure mode during back pressure was used in empirical simulation to determine the safe dimensions of a centrifugal pump shaft when it is subjected to combined stresses and strain due to various loading condition during back pressure.

By combing the system stresses and straining condition during the pump operation, it was possible to design a shaft with more enhanced mechanical properties that can withstand backpressure. In the current study, it was also possible to use the theory of failure mode during back pressure process to simulate and design a unique relationship between stress and strain that impacts material failure during operation. Recent research studies shown limited reports on centrifugal pump shaft failure due to increased in stress and strain during backpressure. It was important to close this research gap by simulating these parameters that impacts shaft failure during back pressure. In this study a centrifugal pump stress and strain during operation are simulated by taking the optimal load on the shaft during backpressure. This was achieved by using an Auto desk fusion 360 in which the parameters that impacts stress and strain were simulated to determine the optimal load on the shaft during operation.

2. Methodology

To simulate and design an efficient shaft that can withstand backpressure during shaft operation, the major stress and straining that often led to material fatigue, the principal stress $\text{maximum principal stress}(\sigma_1) \leq \text{permissiblestress}(\sigma_{per})$ given as $\sigma_{per} = \frac{\text{failure stress}}{\text{factor of safety}} = \frac{s_{yt}}{N} \text{or} \frac{s_{ut}}{N}$ are simulated in the current study. During the simulation process, all factors of safety for the principal stress and strain were taken into consideration by looking at the principal stain of the system and the variation of young's modulus in the system given as,

$$\text{Permissible strain} = \frac{\text{Yielding strain under tensile test}}{\text{Factor of safety}} = \frac{(\varepsilon_{YP})}{N} = \frac{s_{yt}}{EN} \quad [1]$$

The permission strain in the system is impacted by Tri-axial state factors since the Bi-axial factors is assumed to be 0 and the expression is given by equation (2) as

$$[\sigma_1 - \mu(\sigma_2 + \sigma_3)] \leq \frac{s_{yt}}{N} \quad [2]$$

Bi-axial state, $\sigma_3 = 0$

From equation (1) and (2), the effective strain that impacts the system strain energy during backpressure can be computed by looking at the total strain energy in the system during operation and this energy impact the material yield stress during operation. From first principle, the effective strain on the system during backpressure can be computed by looking at the strain factors and strain factors given by equation (3) given as

$$\text{Total Strain Energy per unit volume}(\text{T.S.E./vol}) = \frac{1}{2}\sigma_1.\varepsilon_1 + \frac{1}{2}\sigma_2.\varepsilon_2 + \frac{1}{2}\sigma_3.\varepsilon_3 \quad [3]$$

Where E defined the young's modulus in the system and the young's modulus varying on the system during operation and at the same time the stress intensity and strain intensity on the shaft vary during different load intensity during backpressure given by equation (4) to (6). Equation (4) to (6) defined the Tri-axial state factors during backpressure as given as

$$\varepsilon_1 = \frac{d}{dt}\left(\frac{\mathbf{1}}{E}[\sigma_1 - \mu(\sigma_2 + \sigma_3)]\right) \quad [4]$$

$$\varepsilon_2 = \frac{d}{dt}\left(\frac{\mathbf{1}}{E}[\sigma_2 - \mu(\sigma_1 + \sigma_3)]\right) \quad [5]$$

$$\varepsilon_3 = \frac{d}{dt}\left(\frac{\mathbf{1}}{E}[\sigma_3 - \mu(\sigma_1 + \sigma_2)]\right) \quad [6]$$

Equation (1-14) defined the major parameters and factors used to design the centrifugal pump shaft and these models are simulated simultaneously with an Auto desk fusion 360 and the following results were revealed.

3. Results and Discussion

It was important to perform the relevant simulation for validation purposes. An Auto desk fusion 360 was used to simulate the design shaft during backpressure. The external and internal applied condition on the shaft was used during empirical simulation for a design of a shaft that can withstand an optimal stress and strain during backpressure. During empirical simulation, different colors were revealed by fusion 360 desk during different stress and straining process and failure modes were analyze during backpressure. From the simulated results, the following colors were revealed. Blue color revealed negligible or limited failure mode during shaft operation. The green color revealed a possible failure but the risk to actual failure is very low during backpressure. The yellow color by the auto fusion 360 desk revealed a possible medium failure during backpressure. The orange color revealed a possible high risk to failure during backpressure and red color revealed extreme failure mode due to backpressure.

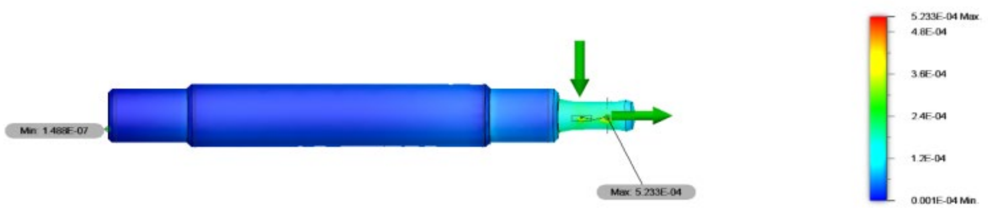

Figure 1 stress and strain impacts on centrifugal pump shaft at a stress/strain of 30 MPa during backpressure

The obtained results revealed by Fig.1 shown the centrifugal pump shaft during operation when subjected to a backpressure of 30 MPa. From the simulated results revealed by Auto diffusion desk 360 it is revealed that there is no possibility that the design shaft can failed during backpressure. It is observed that the shaft is operating at efficient loading condition and the system does not revealed at possibility of failure mode during operation. From the simulation key variables of failure mode analysis, little or no orange color which revealed a possible high risk to failure during backpressure or red color revealed extreme failure mode due to backpressure was noticed from Figure 1. Therefore, the design shaft can withstand the backpressure from the system during operation. Subsequently, the simulation variables were increased as the stress and strain factors increase during operation and the stress and strain intensity on the shaft at 60 MPa was revealed as shown in Fig.2.

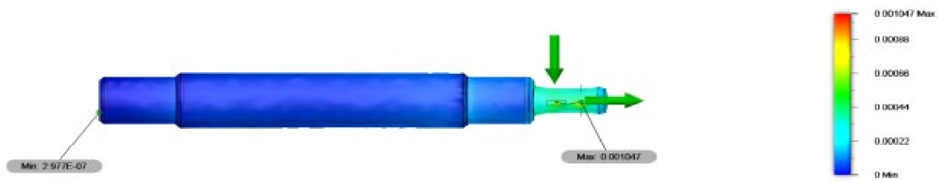

Figure 2 stress and strain impacts on centrifugal pump shaft at a stress/strain of 60 MPa during backpressure

From Fig.2 it is revealed that the centrifugal pump shaft can withstand a yield stress of 60 MPa during operation. The simulated results revealed by Auto diffusion desk 360 revealed a shaft that can withstand a yield stress of 60 MPa during operation. It is observed that the shaft is operating at efficient loading condition and the system is stable and more efficient without any failure mode being reported during operation. From the simulation key variables used in analysis of failure mode rate, little or no orange color was revealed during backpressure and therefore any possible high risk to failure during backpressure or red color revealed extreme failure mode due to backpressure was not revealed during operation as shown in Fig.2. Therefore, the design shaft can withstand the backpressure from the system during operation. Subsequently, the simulation variables were increased as the stress and strain factors increase during operation and the stress and strain intensity on the shaft at 100 MPa was revealed as shown in Fig.3.

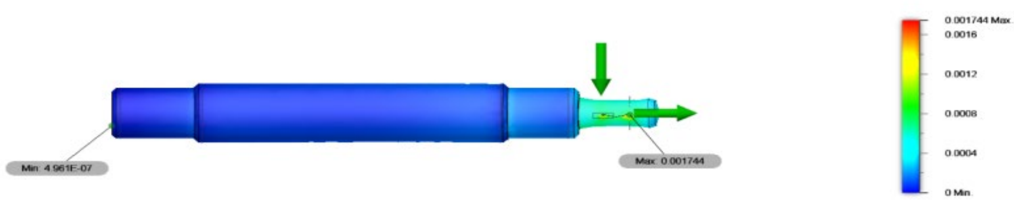

Figure 3 stress and strain impacts on centrifugal pump shaft at a stress/strain of 100 MPa during backpressure

Figure 3 revealed the shaft being subjected to a backpressure of 100 MPa and the material starts to suffer from very little stress or strain that causes material failures were being initiated but at a lower rate which cannot lead to material defects and failure during backpressure. It could be concluded that even at very high yield stress of 100 MPa, the shaft can withstand backpressure during operation. As the stress intensity in the shaft system increases due to increase stress and strain due to distortional factors that impacts strain energy, the shaft does not show any sign of failure during operation. Therefore, the design shaft can withstand backpressure during operation.

4. Conclusion and Recommendation

The aim of the current study was to design a shaft that can withstand backpressure during operation and to achieve that the main factors that impact backpressure which are stress and strain was model and simulated using auto diffusion desk 360 and the following results was revealed. Different colors that revealed different stress intensity and failure modes were used to analyze the design shaft ability to withstand backpressure. It was revealed that the centrifugal pump shaft can withstand a backpressure of 30 MPa during operation without any possibility of failure. From the simulation key variables of failure mode analysis, little or no orange color which revealed a possible high risk to failure during backpressure or red color revealed extreme failure mode due to backpressure was noticed. As the load of stress and strain was increase in the centrifugal pump shaft during operation, little or no failure mode phenomena was reported at 60 MPa and therefore the design shaft was able to withstand a pressure of 100 MPa during operation. Therefore, the designed shaft can withstand backpressure during operation

References

A Barmin1, V. B. (2016). Microstructure and mechaMicrostructure and mechanical properties of silicon carbide ceramics reinforced with multi-walled carbon nanotubesnical properties of silicon carbide ceramics reinforced with multi-walled carbon nanotubes. 7.

A. Pineau a, A. B. (2015). Brittle and ductile fracture.

Abdul, P. D. (2019). Failure Theories.

Akin, J. (2009). Concepts of Stress Analysis.

Ali Naeem Odaa, Y. Y. (2017). Numerical Simulation and Life Prediction of Stepped Shaft Under Biaxial Fatigue Loading.

Almasi, A. (2015). How to Optimize Centrifugal Pump Operation.

AZEEZ, A. A. (2013). FATIGUE FAILURE AND TESTING METHODS.

B. Engel, S. S.-M. (2017). Failure Analysis and Fatigue Life Estimation of a Shaft of a Rotary Draw Bending Machine.

Bansal, R. K. (n.d.). Strength of material.

Bhandari, V. (0000). Introduction to Machine Design.

Bhandari., V. (2010). DESIGN FOR COMBINED LOADING & THEORIES OF FAILURE.

Budris, R. (2016). CENTRIFUGAL PUMP FLOW OPERATING REGIONS AND IMPACT ON RELIABILITY.

D.G. Papageorgiou, K. K. (2018). Fracture analysis of a cooling water pump shaft .

Dimitris G. Papageorgiou, K. A. (2018). Fracture analysis of a cooling water pump shaft.

divedi, h. (2017). MAXIMUM PRINCIPAL STRAIN THEORY.

Dr. B. P. Patel, H. R. (2014). Critical Review on design of shaft with multiple discontinuities and combined,Dutt. B. Thakar.

e, E. n. (2011). transient analysis.

E.R Tomblin, K. B. (2013). CROSS-CONNECTIONS AND BACKFLOW PREVENTION MANUAL.

F. Berndt, A. v. (1999). Pump shaft failures Ð a compendium of case studies.

FAA. (2000). Analysis Techniques.

G.Das, A. S. (1998). Failure analysis of counter shafts of a centrifugal pump.

Gedney, R. (February 1, 2019). Stress-Life Fatigue Testing Basics.
Goran Vukelic 1, *. a. (2016). Predicted Fracture Behavior of Shaft Steels with.
Gulich, J. (2008). centrifugal pumps.
Karney, X. X. (2017). An Overview of Transient Fault Detection.
Kristoffer K. McKee, G. F. (n.d.). A review of major centrifugal pump failure modes with.
KSB. (2018). back pressure speed.
N. Pasca, L. S. (2010). FAILURE ANALYSIS OF A STORAGE PUMP SHAFT.
N.RAJENDAR, .. N. (2017). DESIGN AND ANALYSIS OF COMPOSITE DRIVE SHAFT.
Preven, J. F. (2010). Failure Analysis of Water Pump Shaft.
pvm rao, m. s. (2005). Carbon nanotubes as machine elements. 4.
Richard Leach, . T. (2018). basic of precision engineering.
Rosen, H. (2010). Variability of pump system performance.
Roylance, D. (2001). Introduction to Fracture Mechanics. 2-3.
Roylance, D. (2001). STRESS-STRAIN CURVES.
staff, e. e. (2012). Failure Analysis Of Machine Shafts.
world, w. (2016). RELIABILITY, CENTRIFUGAL PUMP FLOW OPERATING REGIONS AND IMPACT ON.
Wuyi Wan, B. Z. (2018). Investigation on Water Hammer Control of Centrifugal Pumps in Water Supply Pipeline Systems.