Simulating and Optimizing the Stress Distribution on a Centrifugal Pump Shaft due to Varying Backpressure Intensity

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Abstract

Research studies have shown that several centrifugal pump shafts failure are due to the inability to model the optimal stress on the shaft during operation. Most recent studies revealed that the parameters that impacts backpressure have not been properly model for optimal performance during operation. The parameters that impacts backpressure such as stress varying on the shaft are random and therefore the tool of random mechanics can be used to model and simulate the optimal forces during backpressure. In this project the major stresses that impacts backpressure are simulated to determine the optimal stress distribution that a pump shaft can withstand during operation. An auto 360 diffusion desk was used in the modeling and simulation process and the varying stresses on the shaft during backpressure were used to determine the optimal load the shaft can withstand during backpressure. The following results were theoretically derived and validated during modeling and simulation process. It was shown that an increased backpressure during pump operation increases the stress propagation on the shaft spindle and as the backpressure continuous to increased, the key slot stresses increases which leads to an increase in straining that impact shaft performance. The simulated data revealed failure mode after the optimal load on the shaft was exceeded during operation. The obtained simulated results revealed that at extremely high backpressure beyond the optimal stress on the shaft, failure possibility are revealed on the pump shaft and the failure are normally originate slot keyway and propagation of the stress distribution increases during operation

Keywords: optimization, simulation, stress distribution, failure, and backpressure

1. Introduction

The South Africa water supply system uses centrifugal pumps to supply water under very higher pressure. This is mainly due to the landscape of South Africa as water cannot easily flow under gravitation and therefore mechanical centrifugal pump are key in a water supply system in South Africa. In most cases mechanical energy is converted to kinetic energy and the pressure variation are optimize for efficient operation [Krisna Eka Kurniawan,2018]. Amongst the many setback experience by the centrifugal pump such as cavitation, backpressure failure that often leads to mechanical failure is a serious concern that needs a major attention. Backpressure have often led to mechanical breakdown that have often leads to shutdown in most water supply system. Several research attentions are focus towards optimizing the pump operation for efficient water supply during pump operation. Pump instability have been reported to affect the pump performance which affect pressure changeability during pump operation. The instability during pump operation are due to varying stress distribution on the pump shaft during operation. This stress distribution has not been properly model for optimal performance during pump operation. It is important to model the stress distribution in a centrifugal pump shaft for the pump to operate more efficiently during operation [American water works association manual m14. 2004] and water supply generation. It is therefore a need to optimize the stress distribution in a centrifugal pump during operation as this will improve on the system efficiency during operation. Patel, Hiren, Prajapati, Dutt and thakar (2014) shown different effect of backpressure on a shaft and their impact on a shaft during operation. It was revealed that for an efficient operation of a pump system, the backpressure must be optimize for efficient pump operation. Generation, most pump are designed to rotate only in the clockwise direction and the backpressure normally causes the shaft to rotate in the anticlockwise direction in which the shaft was not designed to operate. This normally happened unexpectedly and causes several mechanical damages in a pump system (Patel, Hiren, Prajapati, Dutt and thakar 2014). Most centrifugal pump failure during backpressure since the pump was not designed to operate in this direction. This is a serious problem which needs to be address since pump failure has both economic impacts and social impacts. To address this problem, a pump shaft must be designed to withstand backpressure. To design a pump that will withstand backpressure it is important to understand the stress distribution on the shaft during operation. By understanding the stress distribution on a centrifugal pump shaft during operation, the relevant model of pump optimization during pump operation will be developed.

Several research efforts have been made to optimize the centrifugal pump shaft during backpressure and this was achieved by modeling the hydraulic dynamics in the pump system during operation. In most causes researchers focus on the reversal normal direction of flow due to a downstream pressure during the pump operation. Different factors that impacts the pressure on pipe system drops are model theoretically. Some engineers proposed preventative measures to prevent backpressure and this measure are inefficient due to varying external and internal dynamics being imposed on the shaft during operation. Some of these methods incudes an air gap system, Barometric loop requires, hydraulically operating, mechanically independent pressure-differential relief valve and stop valves which usually bridge the system during backpressure. Most of these are not also efficient as random failure are being reported during pump operation (American water works association manual m14, 2004). More sophisticated methods to prevent backpressure have been use with limited success since mechanical failure due to backpressure are commonly reported. It was revealed that, the most efficient way to prevent backpressure will be modeling the stress distribution on a shaft and designed the desired shaft with the desired mechanical property that can withstand backpressure (E.R Tomblin et al. 2013). In the current study, an attempt was made to model the stress distribution on a centrifugal pump shaft during operation. This led to an empirical model derivation of the optimal stress distribution of a centrifugal pump shaft during operation.

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I. Modelling and Simulation of the optimal stress distribution on a centrifugal pump shaft during operation.

The fundamental principles of backpressure failure can be model by looking at the relevant safe consideration in the shaft during operation under varying stress distribution. The stress distribution on a shaft system depend on the loading forces that impacts the stress distribution during operation. The maximum tensile stress as (Syt) defined by the maximum principal stress$(\sigma_1) \leq$ permissiblestress(σ_{per}) is given as

$$\sigma_1 \leq \frac{S_{yt}}{N} \text{ or } \frac{S_{ut}}{N} \quad [1]$$

The model given by equation (1) revealed the optimal condition for efficient operation and it also depend on the material under all loading conditions. More so, the tri-axial, biaxial and hydrostatic stress are also vital during operation. For a safe design, the uniaxial state of stress is given as ($\tau_{max} = \frac{\sigma_1}{2}$), the Biaxial state of stress when principal stresses are applied is given as ($\tau_{max} = \frac{\sigma_1}{2}$) and the hydrostatic stress condition during operation is 0. Therefore, the maximum stress distribution on the shaft can be computed as

$$\tau_{max} \leq \frac{S_{ys}}{N} or \frac{S_{yt}}{2N} \quad [2]$$

During the pump operation, the system tri-axial state and the bi-axial state of stress is given as, $\sigma_3 = 0$. The model is given as

$$[\sigma_1 - \sigma_2], [\sigma_2 - \sigma_3], [\sigma_3 - \sigma_1] \leq \frac{S_{yt}}{N} \quad [3]$$

$$\sigma_1 - \sigma_2 \leq \frac{S_{yt}}{2N} \quad [4]$$

II. Failure and Distortion analysis during backpressure

The derived models were simulated using an Auto desk fusion 360 and the varying external conditions were applied on the shaft during operation. The varying stress distribution on the shaft was studied and the optimal stress distribution that will lead to shaft failure during backpressure was revealed. The material composition of the shaft and failure mode was given by table 1 and table 2.

Table.1 the material properties in the centrifugal pump shaft

Material	Mild steel
Density	7.85E-06 kg/mm-3
Young modulus	210GPa
Poissons ratio	0.3
Yield strength	207MPa
Ultimate tensile strength	345 MPa
Thermal conductivity	0.056W/(mmC)
Thermal expansion coefficient	1.285E-05/C
Specific heat	480J/(kg C)

Table2. Failure rate analysis in a centrifugal pump during backpressure

failure →				
A	B	C	D	E
Medium 5	High 10	High 15	Extreme 20	Extreme 25
Medium 4	Medium 8	High 12	High 16	Extreme 20
Low 3	Medium 6	Medium 9	High 12	Extreme 15
Low 2	Low 4	Medium 6	High 8	Extreme 10
Negligible 1	Low 2	Medium 3	High 4	Extreme 5

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 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

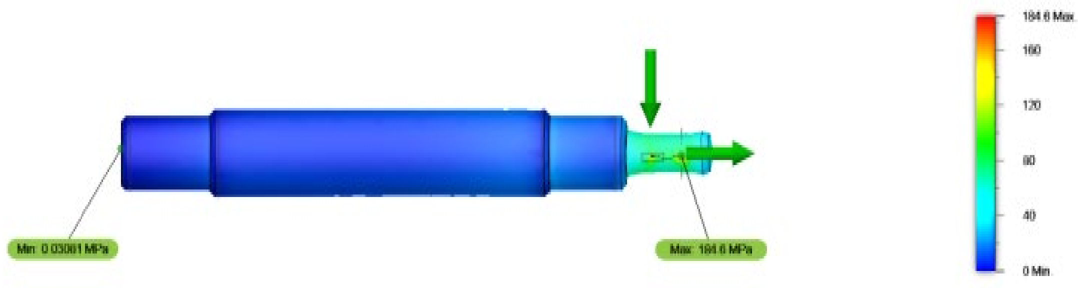

Figure 1: Centrifugal Pump Shaft at varying stress distribution from 50 MPa during operation

Figure (1-3) revealed the effect of backpressure on the shaft during varying stress distribution on the centrifugal pump shaft during operation. The backpressure was revealed from a yield stress of 50 MPa to 100 MPa during pump operation. The simulated results were captured by using Auto desk diffusion 360 and high stress distribution was observed at 50 MPa but the shaft was revealed to be operating free from any failure mode or failure analysis during operation. There is no indication that the designed shaft can withstand a backpressure of 50 MPa during pump operation as no possible failure was revealed. The key slot revealed stable stress distribution and the stresses were being propagated proportionally on the spindle without any abnormal stress distribution being observed. The designed shaft can withstand a max stress of approximately 1846 MPa during operation as revealed in the current study. This is the optimal stress the shaft can withstand at a load of 50 MPa without failure during operation is 1846 MPa. It was important to varying the dynamics load on the centrifugal pump shaft during operation and study the stress distribution and possible optimal load the shaft can withstand.

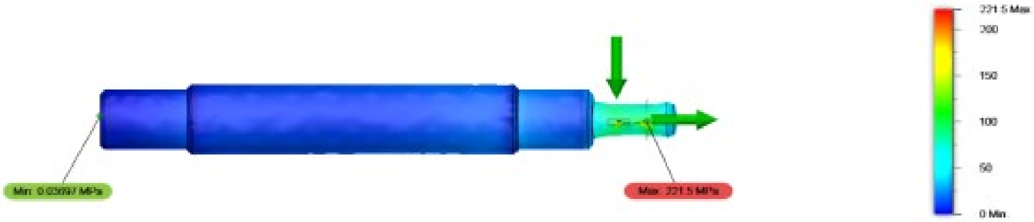

Figure 2: Centrifugal Pump Shaft at varying stress distribution from 60 MPa during operation

Figure (2) revealed the effect of backpressure on the shaft at a load of 60 MPa during the pump operation. The simulated results were captured by using Auto desk diffusion 360 and high stress distribution were analyzed at 60 MPa during backpressure. From the simulated results, it is revealed that the can is operating free from any mechanical failure due to stress distribution that propagates leads to material failure during operation. From the key slot section, it is revealed that the system is very stable with unform stress distribution and the stresses were being propagated proportionally on the spindle without any abnormal stress distribution that can lead to material failure during operation. The designed shaft can withstand a max stress of approximately 2215 MPa during operation as revealed in the current study. This is the optimal stress the shaft can withstand at a load of 60 MPa without failure during operation. It was also important to varying the dynamics load on the centrifugal pump shaft during operation and get the optimal load with optimal stress distribution during backpressure.

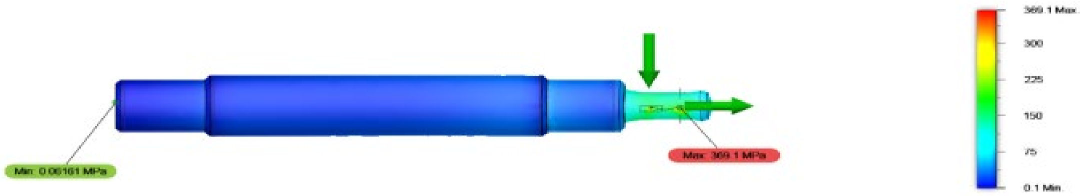

Figure 3: Centrifugal Pump Shaft at varying stress distribution from 100 MPa during operation

Figure (3) revealed the effect of backpressure on the shaft at a load of 100 MPa during the pump operation. The simulated results were captured by using Auto desk diffusion 360 and high stress distribution were analyzed at 100 MPa during backpressure. From the simulated results, it is revealed that the can is operating free from any mechanical failure due to stress distribution that propagates leads to material failure during operation. From the key slot section, it is revealed that the system is very stable with unform stress distribution and the stresses were being propagated proportionally on the spindle without any abnormal stress distribution that can lead to material failure during operation. The designed shaft can withstand a max stress of approximately 345 MPa during operation as revealed in the current study. This is the optimal stress the shaft can withstand at a load of 60 MPa without failure during operation. It was also important to varying the dynamics load on the centrifugal pump shaft during operation and get the optimal load with optimal stress distribution during backpressure. It was revealed as shown in Fig.3 that the backpressure at a stress of 100MPa on the shaft, the fatigue failure mode of the pump shaft due maximum Von Misses at the keyway slot of 369.1 and this exceeded the ultimate tensile stress (345MPa) the shaft can withstand. It was revealed that the Von Misses stress increases, with an increase in backpressure and the keyway slot act as the origin for the pump shaft failure during back pressure.

III. Conclusion and recommendation

The current study was aimed at simulating and optimizing the stress distribution on a centrifugal pump shaft during backpressure. To achieve this objective, the relevant model of stress and stress distribution on a centrifugal pump shaft during operation was model and simulated and the optimal stress distribution was revealed during backpressure. The tool of Auto desk fusion was used to model and simulate the stress distribution on the shaft during backpressure. It was shown that varying stress distribution impacts the shaft mechanical properties and failure mode during operation. It was revealed that the effective backpressure on the shaft was at a given load of 100 MPa during the pump operation. At this load there possible of shaft failure is certain and must be monitor for pump failure to be prevented during backpressure. At a load of 60 MPa to 90 MPa uniform stress distribution was revealed and there was no possibility of mechanical failure due to backpressure. It was revealed that the designed shaft can withstand a max stress of approximately 345 MPa during backpressure. It was shown that, the backpressure at a stress of 100MPa on the shaft, impacted more stress distribution on the shaft and the possibility of fatigue failure mode of the pump shaft due maximum Von Misses was revealed.

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