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Failure Analysis Of Water Pump Shaft

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Abstract- *A water pump shaft for utility water raw material was failed.The shaft was broken into two parts.While in dismantling, the sand was found in chamber between bearing and shaft. There was also a bolt in the impeller. According to reports, the pump has been repaired and since there was no replacement shaft but the shaft was reused in reverse position. There was no inspection of the shaft when it was disconnected by operational reasons. The failure analysis of the broken-shaft was performed to investigate the cause of the failure. Two inspection and analysis were perfomed those are visual inspection and material identification and analysis. When material analysis of the shaft was carried out there was difference between examination and data specification of the shaft.The material identification indicate that the material was AISI SS 304 whereas specification data states SS 316. Both materials have similar tensile stress, so the difference was not the contributor of the failure. The present of foreign material was consider as the cause of the failure. The foreign material caused to stuckedon rotation of shaft and increasing in tensile of the shaft over its ultimate strength.*

Keywords *–vertical pump,tensile stress, ultimate strength, material identification*

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1. Introduction

Well pumpis used to pump ground water that used for process, boiler feed water, and human consumable water.Water contains a lot of iron (Fe), Manganese (Mn), and other minerals. The pump has to deliver water with capacity of 150 m^3/hr and head about 84 meters. By the characteristic of water to be delivered and location, a vertical centrifugal pump was chosen for that requirements.

The vertical pump used at a typical well was design with stainless steel materials. The construction of the pump and details of pump specification can be seen at Fig. 1 and Table 1, subsequently [1].

On November, the pump failed. An information stated that the pump was stop working.After being brought to the shop and initial inspection, it was found that pump shaft broken to near half of the length of the pump shaft, and some impeller parts were damaged at side of the blade. Further moreforeign particles such as sand and new pebbles and bowl bolts casing inside the pump was found.

Based on the information, cause effect analysis was carried out to investigate failure of the shaft.

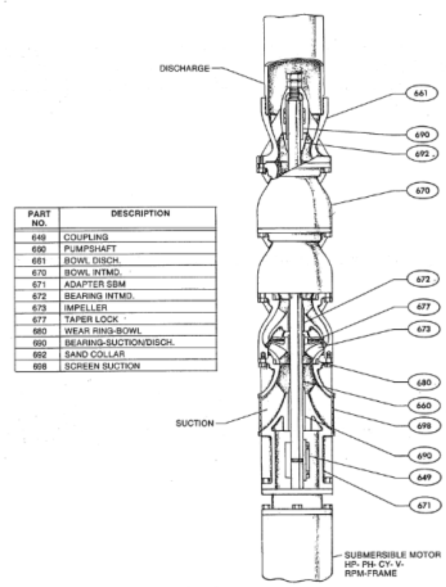


Figure 1. Vertical Centrifugal Pump

Table 1. Specification of Vertical Centrifugal Pump

Manufacture	*: Goulds Pump*
Model	*: VIS*
Size	*: 10 JHC*
No. Stages	*: 5 Stages*
Capacity	*: 1000 GPM*
Head	*: 532 FT*
Liquid Service	*: Ground Water*
SPGR	*: 1,0*
Flow Temperature	*: 25 C at Suction*
Bowl	*: 316 SS*
Impellers	*: 316 SS / Closed impellers*
Pump Shaft	*: 316 SS (Based on pump data sheet)*
Bowl Bearing	*: Bronze (PT Badak use Carbon tape)*
Driver	*: Submersible Electric Motor (PLEUGEUR Manufacturer)*
RPM	*: 2900*
Power	*: 75 KW*
Current	*: 150 at full Load*

2. Analysis Procedure

The procedure to investigate the failure of pump shaft was performed in the steps below [2, 3]:

a. Visual inspection and examination
b. Material Identification

Visual inspection was performed by taking a picture of the failure part of shaft and analysis the form of the broken. The geometry and modes of crack were identify and analyze. In the Material identification step, pump shaft was examine by Olympus Alloy Analyzer that shows the chemical composition of shaft materials. The identified material was used to know its strength of the material, the strength to whitstand tensile occurs in shaft.

3.Results and Discussion

3.1. Visual Inspection and Analysis

Visual inspection was carried out to analyze the modes of failure. One of the picture can be seen at Fig.2. This leading to hypotheses that shaft failed in torsion loading condition.The figure shows that there is a crack initiation. This mode of failure was consider that shaft sustained a rotational load that cause the tensile stress over its ultimate strength. This initial crack was mis-inspection. From historical maintenance data, the shaft was not checked for it.

The cause of the over tensile strength was of the foreign material, those are sand and bolt in pump chamber. The bolt that found in the chamber and damage of impeller can be seen at Fig.4. The rotation of shaft was stucked by the bolt, cause tensile stress increased in the shaft over its tensile strength. The initial crack extents until shaft broken.Besides the stucked, imbalance that cause of bolt exerted in impeller could also be contributor of shaft failure. It can also be seen that their direction of initial crack and failure was different. This is caused by maintenance activity that change the vertical position of the shaft This failure phenomena is similar to that in pump shaft failure studied by some researcher [2, 3, 4, 5].

Figure 2 also shows that the fracture plane was perpendicular to the longitudinal plane of the shaft. It was indicated that crack propagation occurred under induced flexural fatigue loading.

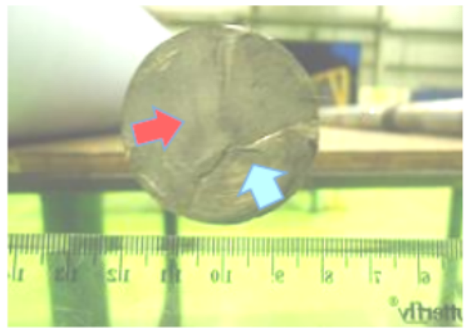


Figure 2. Modes of failure: a. initial crack portion (lower arrow), and b. failure portion (upper arrow)

There are three portion area of the failure, portion that large plastic deformation occurs (large portion), portion of brittle fracture, and portion of rotational bending fatigue charactaeristic.A large portion of the failure surface was flattened and smeared off. This surface condition was considered due to a repeated grinding agains the fracture surface with mating part while the motor runs after complete fracture. The fatigue occurs because of pump operation over 40000 hours without preventive maintenance.

Figure 2 shows that there also was a fatigue zone. The fatigue zone can be described as follows: a smooth rubbed, and velvety appearance, the presence of waves known as "clam-shells" or "oyster-shells", "stop marks" and "beach marks," and the herringbone pattern or granular trace which shows the origin of the crack, as seen at Fig3 [6]. In general, stop marks indicate the variations in the rate of crack propagation due to variations in stress amplitude in a cyclic application varying with time.

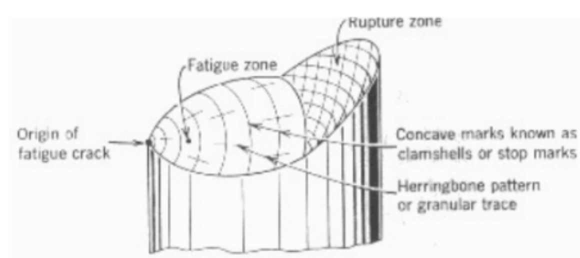


Figure 3. Failure zone

Figure 4. Bolt in pump chamber and damage of impeller

Another cause of failure was worn out of shaft at bearing location, that can be seen at Fig. 4. This wear cause the shaft cross section area reduced and lack to withstand tensile stress. The stress is a high stress level of induce fluctuating stresses that exerts from a start and stop cycle mode of operation. The shaft experiences cyclic flexural load and torsional load during pumping operation. At this location, an excessive plastic deformation could be induced and severe localized stress occurs. This would lead to fatigue crack. The mass of shaft is an factor that induce cyclic flexural stress. This stress is distributed uniformly along the length of the shaft between the bearing supports. At the bearing support, reduced cross section area induces a local stress gradient then this stress could be the contributor to failure of the shaft. The fillet corner was too sharp to withstand the stress concentration for longer duration.

Figure 4. Shaft cross section area reduction caused by wearing out of bearing bushing

Vibratory stress was also suspected as a shaft failure contributor. The existence of sand and bolt in pump chamber could generate vibration. This will induced a vibratory stress subjected to the shaft.

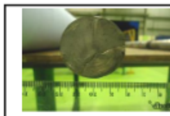
Unbalanced forces which result from foreign material exist in pump chamber could results in large amplitude vibrations. Impellers may shift due to the decrease in residual stresses that are created when the impeller is cooled and contracted around the shaft [7]. Shaft vibrations and flexing tend to result in the impeller cocking or bowing the shaft, which removes it from its original balance along its centerline [8].

3.2. Material Identification

As specification, pump shaft conform to stainless steel SS 316. This material has mechanical properties of yield strength of 21 kg/mm^2.

Material identification was carried out by using alloy analyzer. The identification can be seen at Table 2.

Table 2. Material Identification

	304					
	W	Mo	Cu	Ni	Co	Fe
	Wolfram	Molibdelum	Tembaga	Nikel	Kobal	Besi
	0.045 %	0.234 %	0.424%	8.13%	0.398%	71.04%

The table shows that material identification was stainless steel SS 304. The specification of shaft is SS 316. Both two materials were compare chemically and mechanically. The comparison can be seen at Table 3 and Tabel 4.

Table 3. Material Comparison between SS 304 and SS 316

Standard of Country					Chemical Composition							
USA	German		UK	Japan								
AISI	W-Nr	DIN KURZNAME	BS	JIS	C Max	SI Max	Mn Max	P max	S Max	Ni	Cr	Mo
301	1.4310	X12Cr Ni 177	301S21	SUS 301	0.15	1	2	0.045	0.03	6.00-8.00	16.00-18.00	-
304	1.4301	XDCr Ni 189	304S16	SUS304	0.08	1	2	0.045	0.03	8.00-10.50	18.00-20.00	-
304L	1.4306	X3Cr Ni 89	304S12	SUS 304L	0.03	1	2	0.045	0.03	9.00-13.00	18.00-20.00	-
305	1.4303	X5Cr Ni 1911	305S19	SUS 305	0.12	1	2	0.045	0.03	10.50-13.00	17.00-19.00	-
310S	1.4841	X 15 Cr Ni Si 2520	310S24	SUS 310S	0.08	1.5	2	0.045	0.03	19.00-22.00	24.00-26.00	-
316	1.4401	X15 Cr Ni Mo 1810	306S16	SUS 316	0.08	1	2	0.045	0.03	10.00-14.00	16.00-18.00	2.00-3.00

Table 3 shows that chemical composition of SS 304 and SS 316 is similar. The shaft was made of stainless steel which is a recommended material for such applications[The change of shaft by SS 304 was accepted. It is also for the mechanical properties. The two materials have a same yield strength, that is 21 kg kg/mm^2.

Table 4. Mechanical Properties Comparison between SS 304 and SS 316

USA	German		UK	Japan	Tensile test(min)				Hardness (Max)			
					Y/S		T/S					
AISI	W-Nr	DIN KURZNAME	BS	JIS	kg/mm2	N/mm2	kgf/mm2	N/mm2	Elongat-ion	HB	HRB	Hv
301	1.4310	X12Cr Ni 177	301S21	SUS 301	21	206	53	520	40	187	90	200
304	1.4301	XDCr Ni 189	304S16	SUS304	21	206	53	520	40	187	90	200
304L	1.4306	X3Cr Ni 89	304S12	SUS 304L	18	177	49	481	40	187	90	200
305	1.4303	X5Cr Ni 1911	305S19	SUS 305	18	177	49	481	40	187	90	200
310S	1.4841	X 15 Cr Ni Si 2520	310S24	SUS 310S	21	206	53	520	40	187	90	200
316	1.4401	X15 Cr Ni Mo 1810	306S16	SUS 316	21	206	53	520	40	187	90	200

3.3. Excessive Power

Other main causes of pump failure that could cause excessive power consumption.This could be cause of the liquid that is being pumped has a viscosity that is more than what the pump was designed for. The factors was due to sand and bolt exist in pump chamber.This could lead the shaft to misalign in the pump,and the impeller is touching the case.

4. Conclusion

a. The mode of failure was consider that shaft sustained a rotational load that cause the tensile stress over its ultimate strength..
b. Shaft with material of stainless steel SS 304 could be interchangeable with SS 316, in material properties identification point of view.
c. The existence of sand and bolt in pump chamber could generate vibration. This will induced a vibratory stress subjected to the shaft.

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5. Acknowledgment

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