Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Vibration and reliability of synthesis gas compressors (*A case study in PKT-Kaltim Indonesia*)

Miasa I Made (1), Purwanto Teguh P. (1) and Lacony Erliandy (2)

(1) Department of Mechanical and Industrial Engineering, Gadjah Mada University, Grafika No 2. Yogyakarta, Indonesia
(2) PT. Pupuk Kalimantan Timur, Bontang Kalimantan Timur, Indonesia

PACS: 43.40.At

ABSTRACT

One important factor that affects the productivity of mechanical equipments is their reliability. In this research, the synthesis gas compressor is investigated because most of factory's downtime in Kaltim (East Borneo) Fertilizer Plant is originated from the failure of this component. The objective of this investigation is to find out how the vibration levels of synthesis gas compressors affect their reliability. Two type of synthesis gas compressors were investigated which are System G-1101 and System K-403. System G-1101 consists of 5 sub-systems which are a Low Pressure Turbine (LPT), a High Pressure Turbine (HPT), a Low Pressure Compressor (LPC), a Medium Pressure Compressor (MPC) and a High Pressure Compressor (HPC). Meanwhile, System K-403 has 3 sub-systems which are a Turbine (T), a Low Pressure Compressor (LPC) and a High Pressure Compressor (HPC). Each system has different type and configuration of foundation. The reliability of the system is evaluated using Reliability Block Diagram (RBD) making use of historical maintenance and inspection data collected in the last 10 years. From the data, the reliability of System G-1101 and K-403 for mission time of 2 years is found to be 0.07% and 31.81% respectively. Furthermore, from the comprehensive study on the available vibration data from each sub-system, it was found a strong correlation between the vibration level of each sub-systems and the reliability of the systems, *i.e*. the reliability decreases as the vibration level increases. Furthermore, most of System G-1101 sub-systems have vibration level above of 20µm, which is considered to be beyond the recommended level. This fact is due to poor supporting or foundation type of System G-1101. System G-1101 has a frame type foundation while System K-403 has a block type foundation. This is confirmed by the polar and bode plot of systems' vibration.

INTRODUCTION

One important factor influencing the operation efficiency of an ammonia (fertilizer) plant is the reliability of the machines used in the production process. As one of the biggest fertilizer producers in Indonesia, PT Kalimantan Timur must keep the performance of its plant to fulfil the market demands. One of the equipment that has big contribution to the factory's downtime is the synthesis gas compressor, as can be seen from Table 1.

Table 1. Downtime of ammonia plants in PKT (2003-2006)

No.	Penyebab	K-1	K-2	K-3	K-4	*All Plant*	*All Plant*
		(Days)	*(Days)*	*(Days)*	*(Days)*	*(Days)*	(%)
01.	**Syngas comp**	**55.86**	**2.5**	**0.46**	**6.55**	**65.37**	**15.34**
02.	Other comp	23.18	40.13	-	1.42	64.73	15.2
03.	Static Equip	81.19	14.32	18	51.09	164.6	38.62
04.	Power system	2.37	-	-	6.36	8.73	2.05
05.	External	43.96	17.86	7.19	53.69	122.7	28.79
	Total	**206.56**	**74.81**	**25.65**	**119.11**	**426.13**	**100**

Source: [1]

As can be noticed from Table 1, totally the failure due to static equipment is dominating, however the percentage is not significantly different compared to the rotating equipment (30.54%). Furthermore, the failure of rotating machinery is dominated by the failure of the synthesis gas compressor. Synthesis gas compressor plays important role in ammonia production and considered to be a critical equipment since it does not have the redundancy system. To extend the life and to reduce the failure risk is one of the issues in improving the reliability. For this, an assessment is required to see how an equipment affects the process, the possibility of failure and how to reduce the failure risk [2].

Recently in PT. PKT Kalimantan Timur there are four ammonia plants, which are Kaltim-1, Kaltim-2, Kaltim-3 and Kaltim-4 respectively. Most of the plants have been operated for more than 20 years. In this research, the reliability of the synthesis gas compressors and how the vibration level affects their reliabilities is investigated. Based on this information, a new maintenance strategy can be proposed to increase the reliability of the equipment under investigation.

The investigation is carried out for two synthesis gas compressors, which are System G-1101 in Kaltim-1 d and System K-403 located in Kaltim-3. System G-1101 consists of 5 subsystems which are a Low Pressure Turbine (LPT), a High Pressure Turbine (HPT), a Low Pressure Compressor (LPC), a Medium Pressure Compressor (MPC) and a High Pressure Compressor (HPC). Meanwhile, System K-403 has 3 subsystems which are a Turbine (T), a Low Pressure Compressor (LPC) and a High Pressure Compressor (HPC). In addition, each system has different type and configuration of foundation. These two equipments are investigated because they have a very contrast performance in term of their downtime.

RESEARCH METHODOLOGY

Data collection and verification

The first step in this research is to determine the data source, to collect, to verify and then to process the data. The most important data needed for reliability calculation is the failure rate and failure mode. Table 2 shows the list of data source and type of data.

Table 2. Data source and type

No.	Working units	Data Type	Obtained data
1.	Maintenance	Maintenance card, report	Time to failure
2.	Inspection	Vibration analysis, report	Time to failure
3.	Operation	Asset utilization, production report	Time to failure
4.	Engineering	Modification, Engineering data	Modification
5.	Reliability	RCM, RBI, RCA reports	FMEA

Table 2 shows the working units or divisions from where the data are collected. The reliability of each system is evaluated making use of historical maintenance and inspection data collected in the last 10 years. These data have to be verified or clarified first to ensure the validity of the data. The clarification was obtained from the worker such as supervisor, inspectors, field mechanics, foreman and field operators.

Reliability determination

Based on the collected data, then the reliability of the system can be calculated. In this research, the reliability of the system is evaluated using Reliability Block Diagram (RBD) Simulation Techniques. There are many reports have been published about the use of RBD to evaluate the failure of big and complex systems [3,4,5]. In the analysis of RBD, two softwares which are BlockSim and AVsim from Reliasoft are used because of their ease and accuracy [6].

Vibration data

In addition to the maintenance data used to calculate the reliability, data of vibration measurements were also collected. Figure 1 and 2 show the measurement points where the vibration level for System G-1101 and System K-403 was measured respectively.

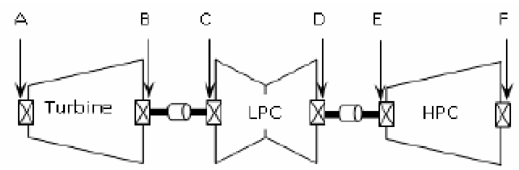


Figure 1. Measurement points for vibration of G-1101

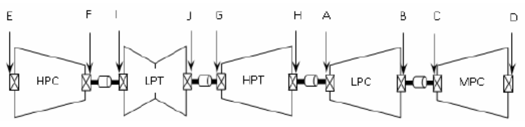


Figure 2. Measurement points for vibration of K-403

The vibration levels in term of displacement in micrometer (μm) were measured at each bearing of the systems. In this study, the measurements data for the last 10 years were used. The values of vibration levels of each system are then compared to their reliability to see their trend.

RESULTS AND DISCUSSIONS

Reliability of System G-1101

System G-1101 consists of 5 machines which are a Low Pressure Turbine (LPT), a High Pressure Turbine (HPT), a Low Pressure Compressor (LPC), a Medium Pressure Compressor (MPC) and a High Pressure Compressor (HPC). The calculation of reliability for mission time of 2 years (730 days) was assumed according to the turn around (TA) program of PT. Pupuk Kalimantan Timur.

Using the Blocksim software, one can obtained the reliability of a machine or equipment up to component level or even down to sub component level. Table 3 shows how the System G-1101 was separated into sub-components.

Table 3. Components and sub components of G-1101

Sub-sistem	*Equipment*	Komponen	Sub-komponen
Turbin	LP-Turbin	5	9
	HP-Turbin	5	9
	Condensing	9	-
Compressor	LP-Compressor	5	10
	MP-Compressor	5	10
	HP-Compressor	5	10
	Separator	3	
	Cooler	7	
Oil	Lube oil	11	
	Seal oil	6	-
	Governing	13	-
	Total	74	48

Furthermore, Table 4 shows the reliability value of System G-1101. The value was surprisingly low which is 0.07% for mission time of two years. This indicated that the system has a big probability of failure during the mission time.

Table 4. Reliability of System G-1101

Sub-system	Block	Reliability *(t=2 years)*	R_S *(t=2 years)*
Turbin	LP Turbin	0.3812	
	HP Turbin	0.1953	
	Condensing	0.5967	0.0444
Compressor	LP compressor	0.3177	
	MP compressor	0.5857	
	HP compressor	0.6434	
	Separator	0.9794	
	Cooler	0.9894	0.1160
Oil	Lube oil	0.993	
	Seal oil	0.9998	
	Governing	0.1309	0.1300
R_S (t=2 years)			**0.0007**

From reliability important analysis, it is noted that governing gave the biggest influence to the value of reliability, followed by HP Turbine, LP Compressor and condenser.

Reliability of System K-403

System K-403 has 3 machines which are a Turbine (T), a Low Pressure Compressor (LPC) and a High Pressure Compressor (HPC). Table 5 shows the number of components and sub-components of the system which are 64 items and 29 items respectively.

Table 5. Components and sub-components of K-403

Sub-sistem	*Equipment*	Komponen	Sub-komponen
Turbin	LP-Turbin	5	9
	Condensing	9	-
Compressor	LP-Compressor	5	10
	HP-Compressor	5	10
	Separator	4	
	Cooler	4	
Oil	Lube oil	10	
	Seal oil	6	-
	Governing	16	-
	Total	64	29

From the calculation of reliability of System K-403 it was found that the reliability value of each sub system's components is above 70%, much better than those of System G-

1101. Finally, as a system, System K-403 has reliability of 31.81% as shown in Table 6.

Table 6. Reliability of System K-403

Sub-system	Block	Reliability (t=2 years)	R_S (t=2 years)
Turbin	LP Turbin	0.8443	
	Condensing	0.7451	0.629
Compressor	LP compressor	0.7606	
	HP compressor	0.9595	
	Separator	0.9726	
	Cooler	0.9601	0.6814
Oil	Lube oil	0.9797	
	Seal oil	0.9998	
	Governing	0.7577	0.7422
R_S (t=2 years)			0.3181

From the reliability important analysis, the equipments with big contribution to the reliability value are condenser, governing and LP compressor.

Vibration trends and reliability

The vibration measurement as shown in Figure 1 and 2 for both systems gave the next results as depicted in Figure 3.

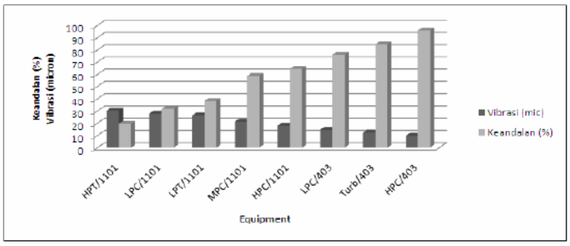


Figure 3. Vibrations and reliabilities of systems

For System G-1101, most of the sub-systems, in this case LPT, HPT, LPC and MPC have vibration level above 20µm. Only HPC has vibration level below 20µm. Meanwhile for System K-403, most of the sub-systems, in this case Turbine, LPC and HPC have vibration levels less than 15µm.

It also can be noticed how the reliability of both systems vary with their vibration levels. From the comprehensive study on the available vibration data from each sub-system, it was found a strong correlation between the vibration level of each sub-systems and the reliability of the systems, *i.e*. the reliability decreases as the vibration level increases. Furthermore, most of System G-1101 sub-systems have vibration level above of 20µm, which is considered to be beyond the recommended level which is 10-15µm [7].

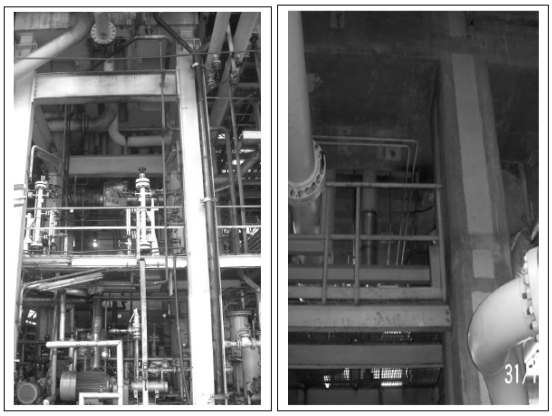
Reliability factor comparison of both systems

To have a clear idea about what actually makes the big different in reliabilities of Systems G-1101 and System K-403, the reliably factor (RF) comparison analysis is carried out. The reliability factor analysis is carried out for design factor, operation factor and installation factor of both systems. The reliability factor of design and operation do not show a significant different for both systems (not shown in this report), indicating that the difference in reliabilities is not closely related to the design and operation factor. However, the reliability factor analysis for the installation shows great differences between the two systems. The comparison results are listed in Table 7. From the comparison of installation reliability factor of both systems, it is obvious that there is a problem in the installation of System G-1101 with RF value of 0.8 for both foundation installation and piping support, which is less than 1 for a system to be considered having an average installation with normal probability of failure and breakdowns [8]. It is predicted that the poor foundation of System G-1101 that leads to the low reliability value of the whole system.

Table 7. Reliability factor comparison

Installation			G-1101		K-403	
No.	Point concern	Equipment	Design	RF	Design	RF
01.	Piping strains	Turbin LP	100 %	1.0	-	-
		Turbin HP	100 %	1.0	100%	1.0
		Compressor LP	100 %	1.0	100%	1.0
		Compressor MP	100 %	1.0	-	-
		Compressor HP	100 %	1.0	100%	1.0
02.	Pipe Support	Turbin LP	Rod hanger	*0.8*	-	-
		Turbin HP	Rod hanger	*0.8*	Spring hanger	1.0
		Compressor LP	Rod hanger	*0.8*	Spring hanger	1.0
		Compressor MP	Rod hanger	*0.8*	-	1.0
		Compressor HP	Rod hanger	*0.8*	Spring hanger	1.0
03.	Expansion joints	Condenser	properly	1.0	Properly	1.0
04.	Foundation	Rigidity	Poor	*0.8*	Good	1.5
		Vibration	Resonance	*0.8*	Rigidity 3X	1.5
		Vib. Isolation	Transmission	*0.8*	No trans	1.5
	Subtotal			**0.17**		**3.38**

Figure 4 shows the real physical condition how the two systems are installed in the plants. System G-1101 uses a frame type foundation using H-beam steel with height of 9m, meanwhile System K-403 uses a concrete-block type foundation with thickness of 1m which is much stronger than the H-beam used for System G-1101.



(a) Struktural G-1101 (b) Struktural K-403

Figure 4. Foundation structures of systems

Failure analysis of System G-1101 with bode plot

In addition to the reliability factor investigation in the previous section, the effect of installation or foundation on vibration plot is also presented. Figure 5a shows the vibration data in polar plot for System G-1101 obtained using ADRE 208 measurement kit. The data was taken for the Low Pressure Turbine (LPT) in start-up condition. It can be seen clearly the effect of weak installation indicated by some loops in polar plot showing resonance problem in this system.

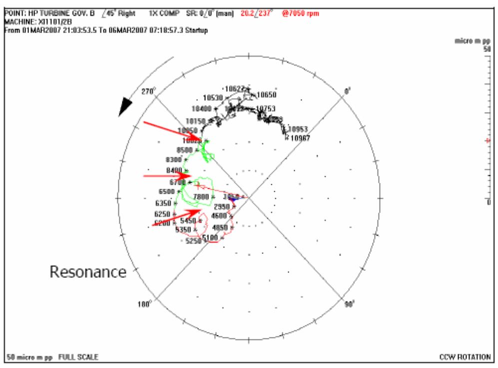


Figure 5a. Polar Plot of LPT G-1101

Furthermore, the bode plot in Figure 5b confirms this phenomena with phase angle change.

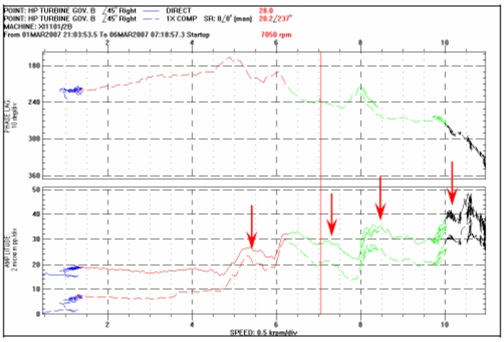
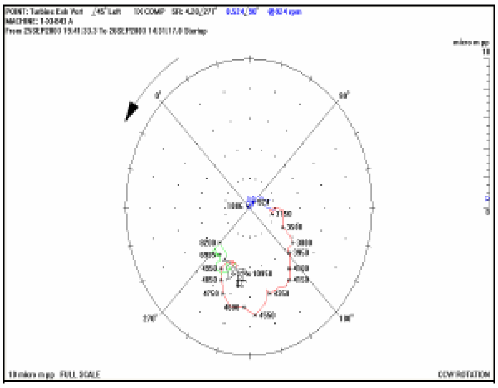
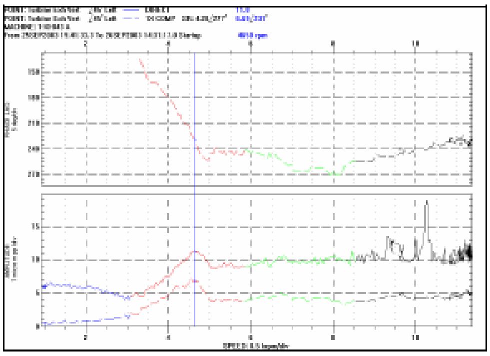


Figure 5b. Bode Plot of LPT G-1101

The same measurement procedure was carried out for System K-403.The results of the measurement are depicted in Figure 6.



(a) Polar plot turbin K-403



(b) Bode plot Turbin K-403

Figure 6. Bode and polar Plot of Turbine K-403

In System K-403, there is only one loop and phase change around 4600 rpm which is the normal operating condition of the rotor.

CONCLUSIONS

The investigations of relation between vibration and reliability of two synthesis gas compressors have been carried out. The reliability of the systems is evaluated using Reliability Block Diagram (RBD) making use of historical maintenance and inspection data collected in the last 10 years. From the data, the reliability of System G-1101 and K-403 for mission time of 2 years is found to be 0.07% and 31.81% respectively. Furthermore, from the comprehensive study on the available vibration data from each sub-system, it was found a strong correlation between the vibration level of each subsystems and the reliability of the systems, *i.e*. the reliability decreases as the vibration level increases. Furthermore, most of System G-1101 sub-systems have vibration level above of 20µm, which is considered to be beyond the recommended level. This fact is due to poor supporting or foundation type of System G-1101. System G-1101 has a frame type foundation while System K-403 has a block type foundation. This is confirmed by the polar and bode plot of systems' vibration.

REFERENCES

[1] Pupuk Kalimantan Timur, PT., "*Asset Utilization Report*" (2002-2007)

[2] Barringer, P.H., " *An Overview of Reliability Engineering Principles*", PennWell Conference & Exhibition, Energy Week, Houston Texas (1996)

[3] Loman, M.J. and Wang, W., "*On Reliability Modeling and Analysis of Highly-Reliable Large System*", 0-7803-7348-0/02, IEEE, pp. 456-459

[4] Wang,W., Loman, M.J., Arno, R.G., Vassiliou P., Furlong, E.R. and Ogden D., " *Reliability Block Diagram Simulation Techniques Applied to the IEEE Std. 493 Standard Network",* 0093-9994/04. IEEE, pp. 887-895 (2004)

[5] Lisnianski, A., "*Extended block diagram method for a multi-state system reliability analysis*", Reliability Engineering and System Safety **92** pp. 1601-1607 (2006)

[6] Reliasoft, "*Life Data Analysis Reference*", Weibull++, Version 7, Reliasoft Publisihing (2005)

[7] IRD Mechanalysis, " *Vibration Measurement and Analysis*", Instruction Manual Training (1980)

[8] Bloch, P.H., and Geitner, K.F., "*Introduction to Machinery Reliability Assesment*", Second Edition, Gulf Publishing Company (1994)