CHEMICAL ENGINEERING TRANSACTIONS
VOL. 46, 2015

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Peiyu Ren, Yancang Li, Huiping Song

ISBN 978-88-95608-37-2; **ISSN** 2283-9216
DOI: 10.3303/CET1546163

Experimental Study of Transducer Harmonics Effect on Pump Unit Energy Consumption

Yin Luo*[a, b], Hui Sun[a], Shouqi Yuan[a], Zhishun Yu[b]

[a] Research Center of Fluid Machinery Engineering and Technology, Jiangsu University, Zhenjiang, 212013, China
[b] Key Laboratory Fluid and Dynamic Machinery Laboratory, Xihua University, Chengdu, 610039, China
luoyin@ujs.edu.cn

Frequency control techniques have been widely applied in chemical processing. However the effects on whole unit energy consumption caused by transducer high harmonics and its additional loss have not been paid enough attention. An experimental study was conducted by using self-priming pump unit as a research object, utilizing NI virtual instrument, and Labview test software and high-frequency electric parameter analyzer. Performance parameters of the pumps and electric parameters of pump system were measured before and after pump unit filtering. Pump unit energy consumption under both circumstances was computed and analyzed. It can be found that unit energy consumption differs from 3% to 6%, while electric motor efficiency differs in 10 percentage points. Pump unit energy consumption difference increases with the loss of frequency before and after filtering. All the above has provided a basis for proper use of transducers and determining the speed range of the pump unit.

1. Introduction

A Pump unit is the main equipment and major energy consumer in a chemical process. With the development of energy conservation and pollution reduction, frequency change and speed adjusting has been increasingly used for saving which was confirmed by Chen (2002) and Luo (2015). However, Chen (2003) et al reported that voltage waveform and current waveform of incoming power will distort because of the high-frequency harmonics created by the variable current loop of transducer input section. The increasing copper and iron loss and mechanical vibration of the pump unit caused by harmonics of motors will result in increase of the whole pump unit system energy consumption and the instability of control system. In the transducer-motor system, it is excessive harmonic currents that lead to the increase of motor heating quantity, reduction of motor lifetime and insulation breakdown of motors, or more seriously cable burst which was confirmed by Francisco (2006) et al.
This paper has adopted NI virtual instrument, Labview test software and a high-frequency electric parameter analyzer to analyze and compare performance parameters of pumps and electric parameters before and after pump unit filtering as well as the effect caused by speed range on the whole pump unit energy consumption

2. Components of transducer harducer harmonics

Usually transducers utilize abundant nonlinear power electronic components such as thyristors. The way transducers absorb energy from the power grid is not a successive sine-wave, but by obtaining current from power grid by pulsation intermittent mode. Such pulsation current and on-way impedance together form pulsation voltage drop superimposing on the voltage of the power grid, which make the voltage distort. According to Fourier analysis, such nonperiodic sine-wave current consists of harmonics whose frequency is not lower than the fundamental wave. Thus, the equations are as follow according to Fuchs (2004).

$$\begin{cases} u_{as} = U_{1m}\sin\omega t + U_{5m}\sin 5\omega t + U_{7m}\sin 7\omega t + ... \\ u_{bs} = U_{1m}\sin\left(\omega t - 120^{\circ}\right) + U_{5m}\sin\left(5\omega t + 120^{\circ}\right) + U_{7m}\sin\left(7\omega t - 120^{\circ}\right) + ... \\ u_{cs} = U_{1m}\sin\left(\omega t + 120^{\circ}\right) + U_{5m}\sin\left(5\omega t - 120^{\circ}\right) + U_{7m}\sin\left(7\omega t + 120^{\circ}\right).... \end{cases} \tag{1}$$

Please cite this article as: Luo Y., Sun H., Yuan S.Q., Yu Z.S., 2015, Experimental study of transducer harmonics effect on pump unit energy consumption, Chemical Engineering Transactions, 46, 973-978 DOI:10.3303/CET1546163

In the equations, $u_{as,}$,, u_{cs} are three-phase voltage instantaneous values. U_{1m}, , are voltage values of the first, fifth and seventh harmonics. From the first equation it can be found that there are no integral harmonics in the voltage instantaneous values. Harmonics of transducers mainly consist of the 5th, 7th, 11th, 13th, 17th, 19th harmonics with no multiple of 3nd harmonics because the three angles of the different phases have 120° difference.

3. Effects of harmonics on the pump units

3.1 Effects of harmonics on the motors

The motor is an important part of pump units. Alternating-current with harmonics will make the performance of motors different from the one supplied by sine-wave power because the frequency power outputs the fundamental as well as the harmonic voltage and current.

High frequency harmonics selected from the stator current will increase stator copper loss. But skin effect resulting from the high-frequency current in the rotor multiplies loss of rotor resistance many times and increases copper loss of rotor resistance. Thus, magnetic and electric load increases while power and power factor decreases when harmonic voltage supplies the asynchronous motor with power which was confirmed by Fuchs (2004) and Carbone (2001).

Harmonic effect can also result in motor ripple in the torque, which generates vibration, noise, makes the pump unit system unstable and finally influences the work of the control system.

Variable frequency drive in the pump unit creates efficiency loss in itself and will increase the temperature of the winding if it generates harmonics in the motor winding which accelerates the damage of motor insulation winding under excessively high temperature for long times.

3.2 Effects of harmonics on the pump unit energy consumption

The equation below can be utilized when quantitatively evaluating N, called pump unit energy consumption according to Tang (2007).

$$N = \frac{\rho g H Q}{367 \eta_P \eta_m \eta_v} \qquad (2)$$

In equation, H-total head, m; Q-flow, m^3/h; η_p-pump efficiency, %; η_m-motor efficiency, %; η_v——transducer efficiency, %.

From the Equ (1) it can be revealed that motor efficiency has influence on the energy consumption of pump units and will decrease because of power and power factor of the motor, which will increase energy consumption of the whole pump unit which was also confirmed by Liu (2006).

Also because the calculation formula of motor efficiency is:

$$\eta_m = P_{out}/P_{in} \qquad (3)$$

$$P_{out} = T^*n/9550 \qquad (4)$$

T-torque, N·m; n-rotating speed, r/min; P_{out}-output power of motor, kW; P_{in}-input power of motor, Kw.

The efficiency of transducer can be regarded as 1 because it is high. Equation 3 and 4 above can be substituted into Equ (2) to get

$$N = \frac{9550 P_{in} \rho g H Q}{367 T n \eta_v} \qquad (5)$$

4. Experiment

During the experiment, performance parameters of the pumps and electric parameters of the pump system can be measured and energy consumption of the pump unit before and after filtering can be analyzed and compared through frequency adjustment by transducer so as to change the rotating speed. Simplified physical model of experiment device is shown in the illustration. The experimental equipment are shown in the Table 1.

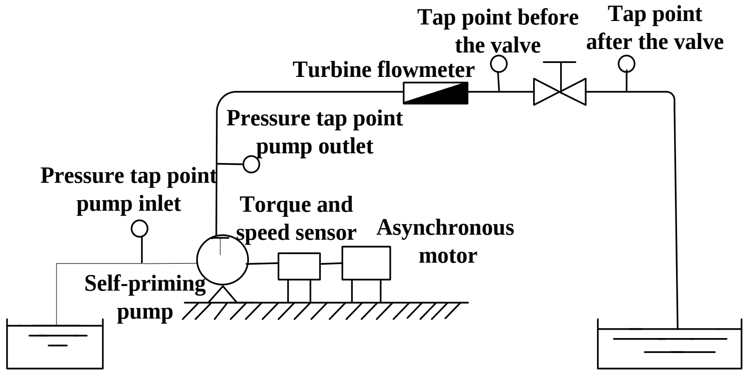


Figure 1: A simplified physic model of the simplified experiment of pump-units system

Table 1: The experimental equipment of pump-units system

Equipment	Parameter
Self-priming pump	Q=15 m^3/h; H=35 m; n=2600 r/min;
Transducer	Mitsubishi FR-F740
Three-phase asynchronous motor	U_{1N}=380 V; P_{1N}=4.0 kW
Torque and speed sensors	Rated load torque 100 N·m; accuracy level 0.2
Pressure transmitter	WT1151GP,accuracy ±0.25%,head±100kP$_a$; accuracy level 0.2
Flowmeter	Turbine flowmeter, accuracy ±0.5%,
Electric parameter analyzer	Qingzhi8962C1

4.1 Comparison of electric parameter waveforms before and after filtering

A RLC sin-wave filter according to Ji (2006) and Su (2003) was chosen for the filtering with the Bode plot as shown in Fig 2.

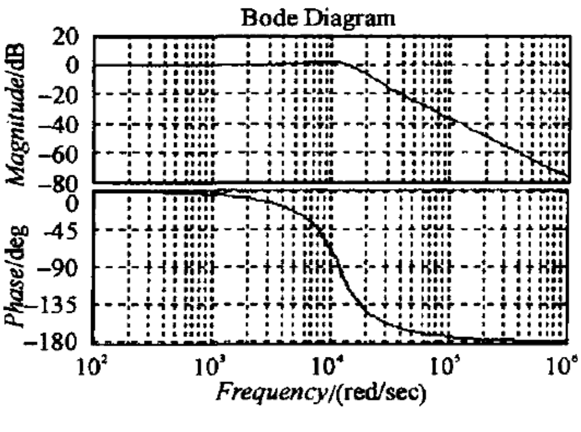
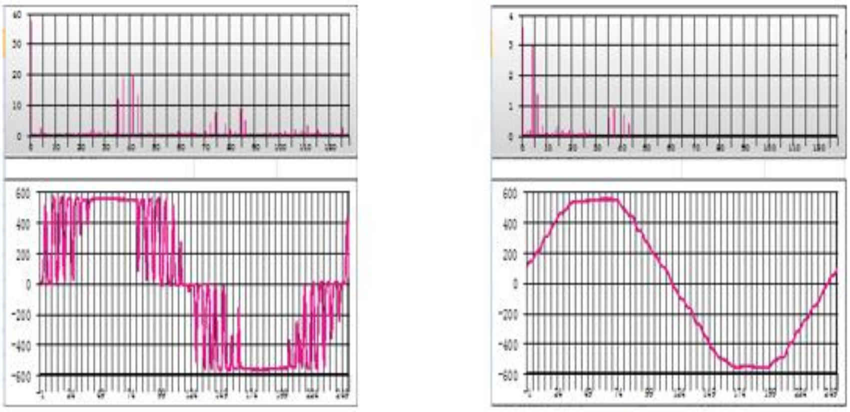


Figure 2: Bode plot of the filter

In the Fig 3 output voltage waveforms of the transducer at 50Hz frequency before and after filtering are compared through the high-frequency electric parameter analyzer. It can be found in the figure that direct output voltage waveforms of the transducer before filtering is not the standard sine-wave but the after one is standard in that intersection point of SPWM waves and triangular carrier generates output voltage and current. It can be analyzed that such voltage waveforms include comparatively high-frequency harmonics through resolving of the Fourier series in the Equ (1).



(a) Before filtering (b) After filtering

Figure 3: A comparison of oscillogram for the frequency converter filtering pre and post under the 50 Hz

4.2 Comparison of pump unit energy consumption before and after filtering

During the experiment of frequency change and speed adjusting energy consumption of the pump unit, the flow of the pump should be at rated flow of 15 m^3/h through adjusting the valve under condition of power frequency. Then adjust the transducer, adjust the rotating speed by changing frequency so as to change performance parameters of pump unit as well as electric parameters of pump system. Performance parameters of the pump in the pump unit can be measured under different frequency as is shown in Table 2. Energy consumption of the pump unit can be calculated before and after filtering through Equation 5 as is shown in the Table 3 and 4.

Table 2: The performance parameters of self-priming centrifugal pump

Frequency (Hz)	Flow (m^3/h)	Torque (N·m)	Rotating speed (r/min)	Total head (m)	Pump efficiency (%)
50	15.09	12.89	2915.19	37.77	40.28
45	13.55	10.43	2618.21	30.49	40.11
40	11.97	8.36	2310.4	23.92	39.38
35	10.41	6.63	2020.16	18.11	37.35
30	8.77	4.84	1713.11	12.93	36.28
25	7.14	3.46	1419.34	8.68	33.51

Table 3: Electric parameters and energy consumption before filtering

Frequency (Hz)	Input power of motor (kW)	Output power of motor (kW)	Efficiency of motor (%)	Energy consumption (kW)
50	4.481	3.935	87.82	4.321
45	3.306	2.862	86.57	4.4
40	2.395	2.021	84.42	4.639
35	1.66	1.402	84.48	4.81
30	1.085	0.868	80.08	5.155
25	0.674	0.513	76.11	5.339

Table 4: Electric parameters and energy consumption after filtering

Frequency (Hz)	Input power of motor (kW)	Output power of motor (kW)	Efficiency of motor (%)	Energy consumption (kW)
50	4.354	3.938	90.44	4.207
45	3.179	2.808	88.32	4.270
40	2.246	2.064	91.88	4.268
35	1.534	1.377	89.76	4.455
30	0.979	0.890	90.91	4.656
25	0.571	0.489	85.79	4.758

Two curves of energy consumption before and after filtering are shown in the Figure 4. With the reduction of frequency, the increasing difference of energy consumption between before and after filtering is approximately 3%~6%.

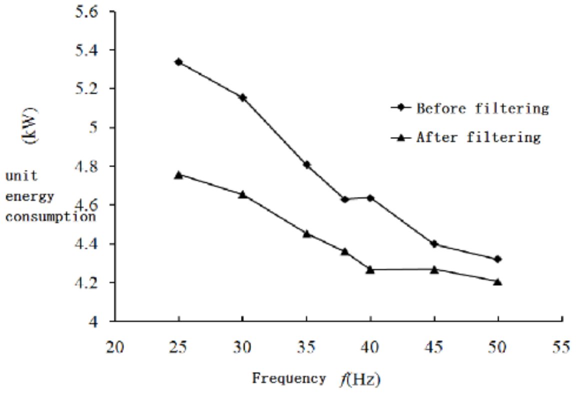


Figure 4: Energy consumption of the pump-units system before and after filtering

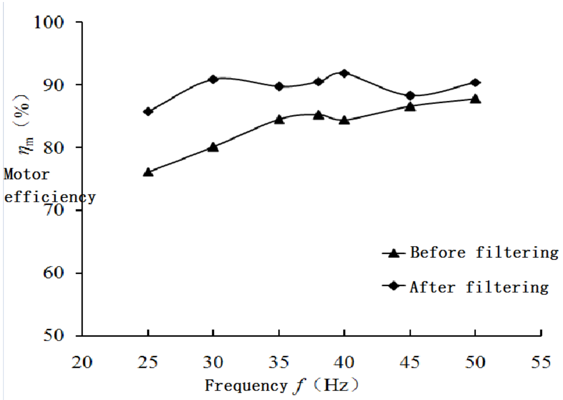


Figure 5: Motor efficiency of the pump-units system before and after filtering

The curves of motor efficiency before and after filtering are shown in the Figure 5. From the figure it can be found that with the reduction of frequency the motor efficiency decreases before and after filtering. Also, motor efficiency differs greater when frequency and rotating speed decrease. That is, the effect of harmonic motor efficiency increases in the low frequency range. Efficiency of the harmonic motor before and after filtering differs in 10 percent when the frequency decreases to 25 Hz. Therefore, filters or reactors should be utilized to cut down the effect of harmonics when using transducers to change the speed of pump unit.

5. Conclusions

1) The effect of transducer harmonics on pump unit energy consumption is studied through experiment, during which the difference of energy consumption between before and after filtering is compared which is about 3%~6%. The motor efficiency differs by 10 percent.
2) Transducers can be utilized to change the speed of a pump. When the rotating speed is high, filters can be chosen. Only one water pump is utilized during the experiment in this paper, which is of reference value for other pump units.

Acknowledgments

This project is supported by National Natural Science Foundation (No. 51409125), the China Postdoctoral Science Foundation (No. 2014M551515), Xihua University (Grant No. szjj2013-006), Jiangsu postdoctoral research grants program (No. 1302026B) University Natural Science Foundation of Jiangsu Province (No. 14KJB470002) and Priority Academic Program Development of Jiangsu Higher Education Institutions.

References

Carbone R., De R.F., Langella R. 2001. A new approach tomodel AC/ DC/ AC conversion systems [C]. IEEE Powerngineering Society Summer Meeting, Vancouver, Canada. 10.1109/PESS.2001.970025

Chen Q.G. 2002. Methods for Calulating and Restraining Steady Harmonic Current and Torque of Induction Motor Equipped with VVVF Converter. Journal of UEST of China, (2): 710-715.

Chen X.Y., Yan B., Xu D.G. 2003. Fuzzy Optimization of Inverter Output Filterin Motor Drive System [J]. Proceedings of the CSEE. 23(8): 71-75

Francisco C. 2006. Harmonics and power systems. CRC press.

Fuchs E.F., Roesler D.J., and Masoum M.A.S. 2004. Are harmonic recommendations according to IEEE and IEC too restrictive? Trans. Power Delivery, 19(4): 1775-1786. 10.1109/PES.2004.1372961

Ji L., Xu T.F. 2006. Interharmonics analysis on static frequency converter system of pumped storage power station. Hubei electric power, (05): 5-7.

Jouanne A.V., Enjeti P., Gnay W. 1996. Application issues for PWM adjustable speed AC motor drives. IEEE Industry Applications Magazine, 2(5): 10-18. 10.1109/2943.532149

Liu Y., Li H.R., Liu X.Y., 2006. Application of variable frequency speed regulation technique in pump control system [J]. Drainage and Irrigation Machinery, 24(4): 44-46, 53.

Luo Y., Sun H., Lu J.X., 2015. Review for sensorless detection technology applied in centrifugal pumps. Journal of Drainage and Irrigation Machinery Engineering, 33(6): 547-552.

Su Q.H., Wu G.Z., Yang C.L., 2002. Study on harmonic suppression of pumped storage power tation with static frequency converter [J]. Journal of Zhejiang University (Engineering Science). (06): 708-712.

Sun C.M., Yuan F. 1999. The Analysis on Harmonic Effect of Asynchronous Motor by Variable-frequency speed control system [J]. Journal of Shenyang Arch. And Civ. Eng. Inst. 15(4): 392-394

Tang Y., Shang Y.B., Wu X. 2007. Energy Consumption Analysis on Constant-pressure Variable-frequency Water Supply and Variable-pressure Variable-frequency Water Supply [J]. Drainage and Irrigation Machinery, 25(1): 45-49

Wu P.L., Zhang X.D. 2002. Research and Application of Energy-Saving Resulted From Frequency Conversion Control in Water-Saving Irrigation System [J]. Transactions of the CSAE. 18(4): 22-25.

Yin L., Yuan S., Yue T., 2013. Research on the Energy Consumption Evaluation and Energy Saving Technical Reconstruction of Centrifugal Pump System Based on Actual Demand. Advances in Mechanical Engineering, 2013, 5(3): 423107-423107. 10.1155/2013/423107