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Vibration cause analysis and elimination of reciprocating compressor inlet pipelines

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ABSTRACT

Due to the occurrence of abnormal vibration of reciprocating compressor inlet pipelines during the commissioning of a booster station, the cause of severe vibration problem was investigated, which included modal analysis, calculation of resonant piping length, velocity frequency spectrum analysis, and pressure pulsation measurement. It was found that the inlet pipelines avoided low frequency resonance region, the actual length of the inlet pipelines was in the second resonant piping length, and the pressure pulsation far exceeded API 618 standard. The results indicate that large pressure pulsation and acoustic resonance occurred on the inlet pipelines are the key factors inducing vibration. Vibration elimination treatments included enlarging the buffer volume of gathering manifold, adjusting the inlet piping length to avoid acoustic resonance, and increasing the curvature radius of bend. After remodeling of the inlet pipelines, the test data indicate that the vibration level of the inlet pipelines is reduced to an acceptable level defined by a relevant standard, and the processing capacity of the booster station can be raised at least two times.

1. Introduction

Reciprocating compressors are widely utilized in the natural gas transmission and natural gas industries because they are flexible in throughput capacity and discharge pressure range. However, large gas fluctuations can be induced because of the intermittent suction/discharge flow. The resulting pressure pulsations in piping system can induce severe piping vibration at a discontinuous region such as elbow, reducer, tee branch or valve. Abnormal or excessive vibrations lead to fatigue failure of piping system, the overloading of the compressor and other safety problems. For example, at a booster station, its design processing capacity was $183 \times 10^4\ m^3/d$, and there were four reciprocating compressors, the power of compressor Nos. 1–3 were 1250 kW, and compressor No.4 was 1030 kW. Due to unreasonable design, the inlet pipelines, as shown in Fig. 1, generated severe vibration. The maximum vibration velocity was 34.26 mm/s, which far exceeded the standard API 618 that is 17.8 mm/s. Worse still, only one compressor could run because of the resulting severe vibration. In order to ensure production, one measure pouring cement on the pipe was taken to control vibration without any rational diagnosis and analysis, as illustrated in Fig. 2. Unfortunately, it could not be controlled radically, there were still severe vibrations. As a result, reducing and controlling vibration level of the piping become significant in engineering.

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Nomenclature

f_{ex}	excitation frequencies related to the rotational speed (Hz)
N	compressor rotational speed, rpm (revolutions per minute)
k	single acting cylinder $k = 1$; double acting cylinder $k = 2$
i	the harmonic order of frequency
M	the transfer matrix
p	pulsation pressure (MPa)
u	pulsation flow velocity (m/s)
ω	angular velocity (rad/s)
L	resonant piping length (m)
a	sound speed of real gas (m/s)
ρ	density of real gas (kg/m^3)
f_0	acoustic frequency (Hz)
k_v	ratio of specific heats
Z	compressibility factor of real gas
R_g	gas constant (J/(kg K))
T	absolute temperature (K)
P_1	maximum allowable level of pressure pulsation ratio (%)
P_L	average absolute pressure (MPa)
ID	inside diameter of pipe (mm)
$[M]$	mass matrix
$[C]$	damping matrix
$[K]$	stiffness matrix
$[F]$	excitation forces (N)

The studies concerning pipeline vibration and pressure pulsation mainly include theoretical research and engineering application. Theoretical research includes building mathematical modeling of pipelines, model parameters calculation, pressure pulsation simulation, fluid–structure interaction conveying fluid and a dynamic response of pipeline [1,2]. The acoustic wave theory, transfer matrix method, and finite element method have been proposed to analyze gas pulsation in the piping system [3,4]. Engineering application mainly focuses on vibration testing technique, vibration analysis technique, fault diagnosis technology, piping design and elimination solution [5,6]. To put an end to the vibration problems, this paper will do model analysis, site measurements and spectrum analysis to discern the key causes of pipe vibration. Meanwhile, according to the key causes and site conditions of the inlet pipelines, some practical elimination measures are going to be taken, and the effect of vibration elimination is to be evaluated after remodeling.

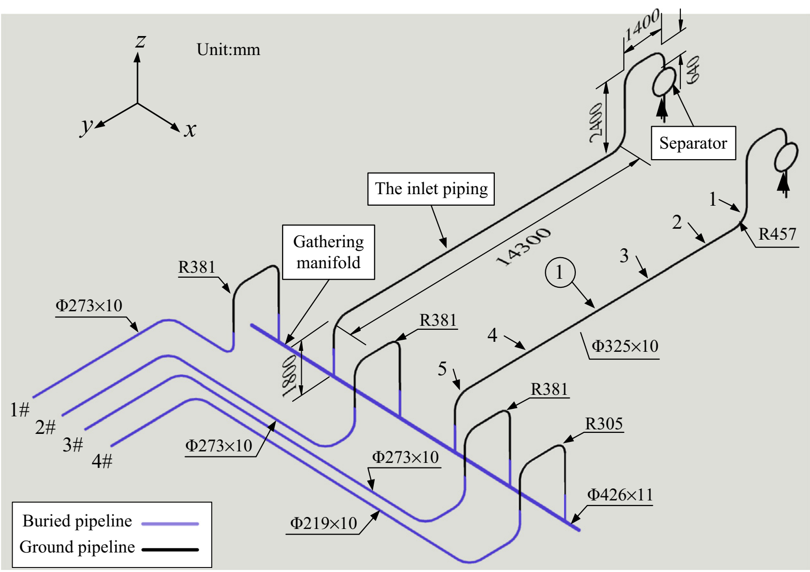

Fig. 1. Layout of the inlet pipelines.