Vibrations at natural gas storage facilities during combined operation of reciprocating and turbo compressors

by

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Abstract:

The current trend for constructing new and revamping existing underground natural gas storage facilities shows that the combined operation of reciprocating and turbo compressors is occurring more frequently. As a part of engineering during the planning phase, exceeding gas pulsations and resulting mechanical piping vibrations should be avoided by theoretical computations. This paper will give an overview of an approach for a procedure when both compressor types are combined. Usually, the theoretical approach has to meet different requirements for each compressor type. It is a well known fact that reciprocating compressors can sometimes cause significant gas pulsations in the connected piping. But what are the possible consequences of these for a turbo compressor that is operated at the same time? The specific aspects due to the combined operation of reciprocating and turbo compressors are discussed.

Due to the situation on the gas market, the technical demands on the equipment for the operation of natural gas storage facilities have increased in the last years. High flexibility is required, especially regarding the amount of natural gas to be stored and withdrawn (thus volume flow) at different pressure ratios. In the recent years, it can be observed that the concept of reciprocating and turbo compressors operating in parallel is being pursued more often, when new storage facilities are constructed (see figure 1) or existing ones are extended and/or revamped. It is a well known fact that reciprocating compressors can sometimes cause significant gas pulsations in the connected piping. But what are the possible consequences of these for a turbo compressor that is operated at the same time?

Figure 1: Construction of a new natural gas storage facility.

A so-called "pulsation study" is often performed for new facilities with reciprocating compressors. Using theoretical models, the expected pulsation level due to the oscillating compressor is predicted. Being performed during the planning phase, the aim of the pulsation study is to avoid high gas pulsations and accordingly mechanical vibrations of the piping caused by pulsations. At the heart of the study is the acoustic modelling of the pulsation source itself, i.e. the cylinders of the compressor. Based on technical drawings of the reciprocating compressor, acoustic models are built for the piston, the cylinder, the valves and the gas passages. Subsequently, models are made for the piping, the dampers, the coolers, the gate valves etc. The API standard 618 (Reciprocating Compressors for Petroleum, Chemical and Gas Industry Services, API standard 618, 5th edition, 2007) describes the way and the extents of pulsation studies and gives guidelines for allowable pressure pulsations. Typically, the gas pulsations occur at the rotational frequency of the compressor (typically 200 rpm up to 1,000 rpm) and multiples of this (the higher harmonics).

The situation is different for studies for turbo compressors. The compressor's rotational frequency and blade passage frequency (rotational frequency x number of blades) does not play an important role in the occurrence of piping vibrations. Firstly, the excitation frequency range lies distinctly higher, with rotational speeds between 6,000 rpm and 15,000 rpm. Secondly, because of the different mode of operation of the turbo compressor, the pulsation amplitudes are small compared to those caused by a reciprocating compressor. During normal operation of turbo compressor facilities, undesired pressure pulsations in the piping are primarily caused by flow induced excitation. They are mainly caused by vortex shedding at T-joints, where a non-flown through side branch is "whistled". The vortex shedding frequency depends on the geometry and - among others - on the flow velocity. When the frequency of the vortex shedding is the same as the acoustic natural frequency of the side branch (coincidence), high gas pulsations can occur (acoustic resonances). Especial critical are those acoustic resonances that occur close to structural natural frequencies of the piping system.

Summing up, the pulsation studies for both different types of machines reciprocating and centrifugal compressors follow a different approach. But when in a new or in an extended facility both compressor types are implemented, it is obvious to connect both approaches. Initially, both types of pulsation study are performed more or less separately. That means: 1. Investigating the gas pulsations caused by the operation of the reciprocating compressor and 2. Investigating the flow induced excitation that occurs during operation of the turbo compressor.

For this, the complete piping system on the suction and discharge side of the compressor is considered. Thus, also the pressure pulsations caused by the reciprocating compressors at the connecting flanges of the turbo compressors are calculated. For the parallel operation with a turbo compressor, whose steady operating point lies close to the surge line, these pressure pulsations should not exceed this limit. As a conservative approach for an allowable pulsation level at such an operating point, the margin can be used that exists between operating point and surge line for steady operation of the turbo compressor, see figure 2.

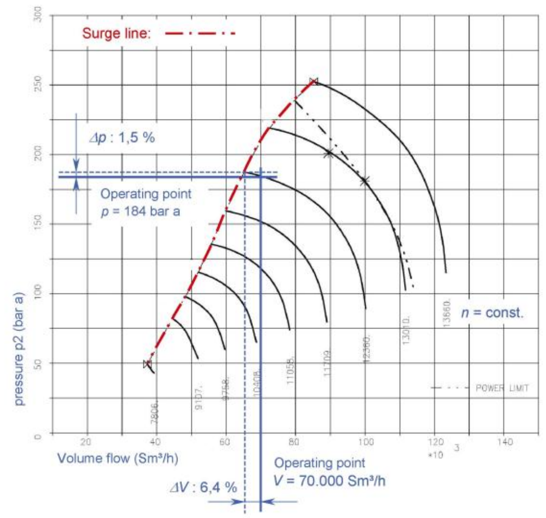

Figure. 2: Performance map of a turbo compressor with an operating point close to the surge line – Example of assigning allowable pressure and volume flow pulsations.

For natural gas storage facilities, which shall be extended, it is a fundamental advantage to investigate the pulsation and vibration levels of the status quo by measurements in the non extended plant before performing the calculations. Independent if the extension involves a reciprocating or centrifugal compressor. Because firstly, measurements can reveal sections with critical vibration levels. The second reason is that measurements can validate and tune the acoustic modelling for the existing facility. With this, reliable statements can be made for the extended facility. In the past, the combination of measurements and modelling has shown to be beneficial especially for older facilities. Uncertainties in the modelling due to lacking information of the older facility could thus be compensated.

The structural piping layout close to a turbo compressor is often relatively flexible, e.g. when the connecting pipeline “descends from above” towards the compressor. Such a pipeline section is relatively susceptible for excitation by pressure pulsations from a parallel operating reciprocating compressor. Therefore, these sections are generally examined more closely in the structural-mechanical calculations of a pulsation study. For the assessment of vibrations due to gas pulsations, the acoustic forces at e.g. bends and T-joints, which are calculated in the acoustic study, are used as excitation (input) for the structural mechanical model, see figure 3.

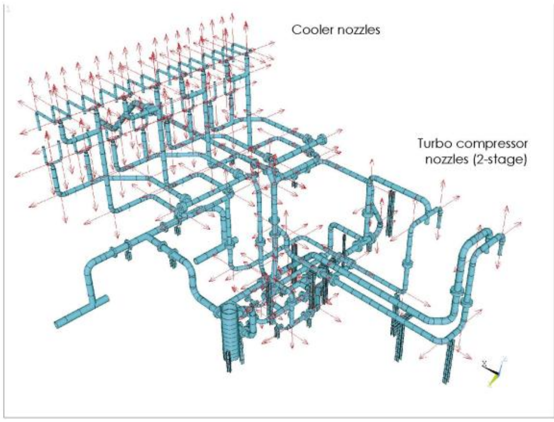

Figure. 3: Structural-mechanical model (FEM) of a piping system near a turbo compressor – the arrows indicate the exciting gas pulsation forces.

In case the structural mechanical calculations show that the allowable guidelines (for vibration velocity, vibration displacement or the dynamic part of the stresses in the material) are exceeded, the guidance of the piping can be modified, e.g. by adding a support or by increasing the stiffness of an already existing support etc.

The experience with pressure pulsation and piping vibration measurements after start-up of natural gas storage facilities shows that the parallel operation of reciprocating and turbo compressors can be in principle trouble-free (from the vibration-technical point of view). However, it remains recommendable to carry out a pulsation study during the planning phase, which is adapted to the requirements for both machine types and if necessary to carry out measurements upfront.